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THESIS

ACTUAL AND PERCEIVED COGNITIVE PERFORMANCE DURING ACUTE ALTITUDE EXPOSURE

Submitted by

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In partial fulfillment of the requirements for the
degree of Master of Science

Colorado State University
Fort Collins, Colorado
Fall 2001

COLORADO STATE UNIVERSITY

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY LAURA C. TERRY ENTITLED ACTUAL AND PERCEIVED COGNITIVE PERFORMANCE DURING ACUTE ALTITUDE EXPOSURE BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

Committee on Graduate Work

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ABSTRACT

ACTUAL AND PERCEIVED COGNITIVE PERFORMANCE DURING ACUTE ALTITUDE EXPOSURE

Observations by aviators and mountain climbers who attempt to ascend above 10,000 to 14,000 ft will often include references to impairments of cognitive abilities. Although known cognitive impairments occur at altitude, little has been done to research the perception of such decrements in performance. The purpose of this study was to evaluate potential differences in actual and perceived cognitive performance at moderate altitude (10,000 ft and 14,000 ft) under several environmental conditions. Ten subjects were exposed to each altitude condition on separate days and asked to perform a computer test, SYNWIN, while at rest at ground level (5,000 ft), at rest at altitude, after 10 minutes of exercise at altitude, and while breathing supplemental oxygen at altitude. Before and after each test at altitude, subjects were asked to provide pre- and post-test estimates regarding their performance on the cognitive test by rating their performance on a five-point scale, as compared to the most recently completed test. It was hypothesized that cognitive performance at 14,000 ft would be worse than that at 10,000 ft, with the difference exacerbated after exercise, but then eliminated by supplemental oxygen. It was also hypothesized that over-confidence would also manifest itself, to degrees corresponding to the hypothesized decrements in performance.

Actual performance on the test was significantly greater at 10,000 ft compared to both ground level and 14,000 ft while at rest. Performance at 10,000 ft was also

significantly greater than that at 14,000 ft after exercise and oxygen supplementation. Post-exercise scores were significantly greater than pre-exercise scores, regardless of altitude. Performance while breathing supplemental oxygen was significantly greater than without oxygen, also regardless of altitude.

Subjects were unable to accurately predict their performance on the test prior to taking the test regardless of test condition. Under-estimation was prevalent for the resting and post-exercise test, while over-estimation was common while breathing supplemental oxygen. After taking the test, the subjective performance estimates showed better correlations with actual performance changes, but no obvious trends (such as marked blocks of correlations while breathing supplemental oxygen) were apparent.

Based on the improvements in performance following exercise and oxygen, both protocols could be recommended to pilots prior to or during crucial portions of the flight. Although over-confidence tendencies while on oxygen should be noted, the actual benefits to performance outweigh potential risks. Further research is needed to elucidate the cause(s) behind the increased performance at 10,000 ft. The beneficial effects of exercise and oxygen supplementation should be tested under more real world situations (such as flight simulators) to more closely examine the cognitive improvements. Additional work on subjective estimation of cognitive performance at altitude could provide significant findings for a variety of fields, such as aviation, mountaineering, and high-altitude work.

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Fall 2001

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CHAPTER I

INTRODUCTION

Much attention has been devoted to physiological changes that occur at extreme altitudes (greater than 20,000 ft); however, few studies have been conducted to examine cognitive changes, especially associated with mild to moderate hypoxia (found from 8-14,000 ft). Such levels are especially relevant to pilots of unpressurized aircraft or rescue helicopters, workers such as miners or astronomical observatory personnel, and recreational mountain climbers who often challenge the numerous "fourteeners", many of which are located in Colorado.

Although decrements in cognitive performance are equivocal below 10,000 ft, there is general agreement for initial signs of hypoxia occurring above this altitude and certainly above 12,000 ft. Such estimates are often made with subjects who are tested under resting conditions. However, even mild exercise can complicate the issue and effectively raise the body's perceived altitude (as measured by a greater reduction in arterial O_2 saturation) to well above 14,000 ft.

The brain uses oxygen at a rate of about 3-ml/100 gm/min, which is equivalent to approximately 20% of the body's resting oxygen consumption (Hultgren, 1997). The brain can only tolerate limited reductions to this requirement before various mental functions become impaired. These functions include associative memory, perceptual speed, knowledge-based tasks, vigilance, motor speed, and visual function. Numerous assessment tasks have been developed to quantitatively evaluate changes in such

functions. Comparisons between different tests show that mild hypoxia yields varying degrees of impairment on different cognitive functions.

Although such decrements in cognitive function are unavoidable, Heath and Williams (1979) reported that such impairments can be overcome by motivation and training. Philips et al. (1963) reported that among other factors, the ability of the individual to respond to awareness of physiological deficits by increased effort can determine performance under hypoxic conditions. An underlying assumption to both of these statements is that the individual can accurately assess that such decrements are occurring and can respond with increased effort accordingly. Unfortunately, this may not always be the case. At extremely high elevations, and presumably to a lesser extent and moderately high elevations, overconfidence is frequent and can lead to life threatening mistakes and misjudgments.

To my knowledge, no studies have been conducted to determine the "perception" of potential cognitive deficits compared to actual measurements of cognitive deficits. If a difference between the two is evident, then this may explain some of the accidents that occur at intermediate altitudes. There were several specific aims of this study:

- To evaluate potential differences in actual cognitive performance under a variety of conditions when exposed to moderate altitude including:
  - Ground level compared with 10,000 ft and 14,000 ft
  - The effects of exercise at altitude
  - The effects of oxygen supplementation at altitude
- To evaluate potential differences between subjects' perceived cognitive abilities and their actual cognitive abilities.

This study tested the hypothesis that hypoxic individuals overestimate their cognitive abilities. A comparison between subjective self-evaluation of cognitive ability with quantitative assessment of cognitive ability by measuring performance with a battery of tests was conducted. The study was designed to most closely simulate conditions that rescue pilots or military pilots delivering ordinances might face when conducting operations at intermediate altitudes.

CHAPTER II

LITERATURE REVIEW

AVIATION

History

The most important single hazard of flight at high altitude is hypoxia (Ernsting, 1984). Perhaps the first example of the hazards of ascent without oxygen, which still has its lessons for present-day aviation, is the tragic ascent of the balloon Zenith, in 1875, when acute hypoxia claimed its first two victims (West, 1998). Gaston Tissandier and his two colleagues had a supply of oxygen aboard their craft, but, in order to conserve it, they delayed breathing the gas until they were so affected by hypoxia that they were unable to do so. Remarkably, Tissandier survived the incident.

The first serious work towards the achievement of a pressurized cabin was done in the United States in 1921; however, it was not until 1939 that the United States flew it's first successful pressurized aircraft (Greenwald and McIver, 1967). Today, all commercial aircraft must be capable of maintaining cabin pressures no higher than 8,000 ft, although actual airline regulations are more complicated and lenient, allowing cabin pressures up to 10,000 ft (Cottrell, 1988). This regulation was established by the maximum degree of hypoxia that would be acceptable for the flight deck crew or passengers (Ernsting, 1978).

Current Regulations

The current regulation regarding flight at high altitude in the United States for civilian aircraft, as stated in Federal Aviation Regulation 91.211, is stated below:

> "(a) *General.* No person may operate a civil aircraft of U.S. registry- (1) At cabin pressure altitudes above 12,500 ft mean sea level (MSL) up to and including 14,000 ft (MSL) unless the required minimum flight crew is provided with and uses supplemental oxygen for that part of the flight at those altitudes that is of more than 30 minutes duration…"

According to many sources, this regulation is too lax and Ernsting (1984) suggests that it should be amended to reduce the maximum altitude at which pilots can breathe air to, and perhaps below, 10,000 ft. In the United Kingdom, regulations are more restrictive, requiring oxygen for flights over 30 minutes at altitudes between 10,000 ft and 13,000 ft (Ernsting, 1984).

It is interesting to note that military regulations are much more stringent. Royal Air Force Regulations do not permit aircraft without oxygen equipment to fly above 10,000 ft, and where practicable, they are not to be flown above 8,000 ft (Ernsting, 1984).

The Dilemma

There are numerous benefits to flying at altitudes only tolerable in pressurized cabins, including decreased fuel costs and avoiding surface weather. However, the greater the differential pressure across the wall of a pressurized cabin, the stronger and heavier the structure must be. Thus, planes not designed for such altitudes may be lighter and built at far reduced costs. Although mechanical limitations and fuel considerations

often limit flight at altitudes above 10,000 ft, in higher parts of the country this is often not the case.

In the mountain states, aviation death rates are twice the rate of the United States as a whole (Baker and Lamb, 1989). Many crashes involve poor pilot judgment and even experienced pilots exhibit poor judgment on occasion. Although aircraft performance at high altitudes undoubtedly plays a major role in this statistic, it cannot be ignored that pilot performance may also be affected and partially responsible for these fatalities.

Other Implicated Parties

The concerns regarding the effects of mild degrees of hypoxia on human performance are obviously well deserved, and several studies were conducted before and during WWII. McFarland (1971), who conducted many of these studies, concluded that the effects of hypoxia upon cognitive function only become significant above 10,000 ft. With ascent from 10,000 to 15,000 ft, there is a progressive impairment of alertness, memory, computation, and attention. Aviators are not the only group affected by high altitude in potentially dangerous ways.

As stated by West (1992), the mountaineering literature is full of examples of irrational decisions. From anecdotal reports of many climbers, it is clear that a number of poor decisions have been made because of impaired cerebral function. Although hypoxia is just one among a variety of factors in mountaineering (such as unfavorable environmental conditions, food and water deprivation, and physical exhaustion), it cannot be ignored.

Hypoxia is also a common, but usually unnoticed, event occurring during the postoperative experience of many surgical patients (Noble et al., 1993). Periods of

desaturation (SaO_2<85%) can last many hours, especially during sleep and following the administration of opiate drugs. Critical decisions are generally not required of such patients and thus hypoxic effects on cognitive function are usually ignored.

HYPOXIA

Physiological Responses

A deficiency of oxygen reaching body tissues or cells is known as hypoxia. Although this can occur from a variety of causes, the factor most often encountered is the reduction in the partial pressure of oxygen (PO_2) as a result of the reduction in total atmospheric pressure that occurs with increasing altitude. Breathing ambient "air" at reduced total barometric pressure reduces the PO_2 and thus reduces the pressure gradient between the alveoli and mixed venous blood. As a result, less oxygen diffuses across the alveolar-capillary membrane into the blood. Because of this, blood will leave the pulmonary capillaries with lower PO_2s than normal. This in turn reduces the gradient driving oxygen into tissues, providing the basis for the impairments caused by hypoxia. Symptoms and behavioral manifestations occur with greater probability during higher altitude exposures.

Hyperventilation is the primary means of preventing hypoxic cognitive impairments, by increasing O_2 uptake to counter the low ambient PO_2. However, hypoxia dilates cerebral blood vessels when carbon dioxide tension is maintained at a constant level. Hypocapnia, however, has a powerful vasoconstrictive effect upon the cerebral circulation. Thus, two opposing factors are constantly active, with consequent effects upon cerebral function.

Cerebral Emphasis

The brain only comprises 2% of the body's weight, but it consumes almost one-fifth of the total oxygen uptake (Cavaletti and Tredici, 1992). A relatively constant and high supply of oxygen is necessary for normal functioning. The oxygen delivery to the brain can vary markedly from one individual to another (Ernsting, 1984). Oxygen delivery from cerebral capillaries depends not only on the concentration and PO_2 in the blood, but also on the relationship between blood flow through the capillaries and local oxygen consumption. Marked changes in cerebral blood flow generally prevent hypoxic energy failure. These changes are induced by both hypoxia and hypercapnia and are accomplished by vasodilation. One of the characteristics of the cerebral circulation is that a reduction of the partial pressure of carbon dioxide (PCO_2) in the arterial blood reduces the blood flow through the brain. Thus hyperventilation, and the resulting drop in PCO_2, can decrease cerebral blood flow and decrease oxygen delivery as blood flows through cerebral capillaries. Although hyperventilation raises the PO_2 of the blood coming from the lungs, the vasoconstriction of the cerebral vessels, due to decreasing PCO_2, results in reduced oxygen delivery to brain cells. Thus, under mild hypoxia, the degree of tissue hypoxia could vary markedly between individuals depending on the ventilatory response (also influenced by conditioning, genetics, etc).

According to Gibson et al. (1981), unlike severe hypoxia, which impairs the supply of energy for the brain, mild hypoxia does not alter the levels of ATP. However, the turnover of several neurotransmitters is altered, including acetylcholine. Acetylcholine synthesis is reduced proportionally to the reduction in carbohydrate oxidation. Acetylcholine has an important role in mediating the cerebral effects of mild

hypoxia and is involved in the regulation of learning and memory processes. Thus, mild hypoxia can alter cognitive ability by lowering the levels of important neurotransmitters.

Altered Cognitive Abilities

Minimum Altitude

As experienced by Tissandier and his two colleagues, consciousness can only be maintained for a few minutes after rapid exposure to altitudes above 20,000 ft. At 15,000 ft, cognitive function is impaired, euphoria and/or irritability appear, critical judgement fails, and muscular incoordination may become evident (Gibson et al., 1981). Below 15,000 ft, however, impairments are more difficult to quantify, but can include effects on concentration, short-term memory and the ability to learn complex tasks.

The minimum altitude at which cognitive and psychomotor performance is significantly impaired remains a controversial issue. Traditionally it has been accepted that visual functions (predominately dark adaptation) are particularly sensitive to hypoxia with effects on the visual threshold being found at an altitude as low as 5,000 ft (Fowler et al., 1985). However, the altitude at which these visual decrements, along with direct effects of hypoxia on neural tissue, influence performance on more complex tasks is equivocal. In a review of hypoxia literature between 1950 and 1963, Tune (1964) tentatively concluded that significant impairments in perceptual-motor performance occur at 10,000 ft. He also issued a plea for more rigorous experimentation and suggested further investigations elucidating the effects of exposure to a specific altitude.

An early study by Denison et al. (1966) found decrements in cognitive performance at 5,000 and 8,000 ft. These results have never been replicated and review of the experiment points to the novelty of the task, combined with physical exertion of

pedaling a cycle ergometer while doing the task, as other contributing factors. Many agree that the ability of a subject to learn a novel task is impaired when breathing air as low as 8,000 ft compared to ground level (Billings, 1974). Although some studies refute this claim, it is often cited as a reason to lower cabin pressurization requirements based on safety concerns for pilots who encounter unrehearsed, emergency situations (Ernsting, 1978; Ernsting, 1984).

In a series of experiments conducted at simulated altitudes of 12,000 ft, results have been ambiguous regarding task-performance impairment. Kelman and Crow (1969) found a decrement on a task requiring detection of sequences of alphabet letters in a series, but no significant effect on either a card-sorting task (Kelman et al., 1969) or a short-term memory task (Crow and Kelman, 1971). Repeating the study in 1973, the authors could neither replicate their earlier positive finding nor show any significant effect on word recall (Crow and Kelman, 1973).

By investigating arterial oxygen saturation (SaO_2) values, Fowler et al. (1985, 1987) attempted to examine the discrepancies between the studies listed above. By modulating the breathing mixtures of the subjects to reduce their SaO_2 values in 2% increments, they found that response times slowed in a step-dependent manner. They identified a SaO_2 threshold of 83%, which they reported equivalent to 9750 ft, as the threshold for which performance decrements were found, partially as influenced by a disruption of vision. Noble et al. (1993) found significant impairment at a mean SaO_2 of 78% on simple reaction-time tests.

All of these tasks, however, have been abstract, single-item activities. Other studies have used complex or multiple, time-shared tasks or simulated flight activities in

their design. Using a flight simulator, Gold and Kulak (1972) recommend supplemental oxygen for any crewmember involved in a complex task at or above 12,000 ft. Nesthus et al. (1997) found that significantly more procedural errors were committed during simulated cruise flight, ascent, and descent from 10,000 ft in individuals without supplemental oxygen compared to the normoxic control group. However, Pearson and Neal (1970) found no impairment induced by hypoxia at 12,000 ft at two-dimensional compensatory tracking, auditory vigilance, or serial problem solving.

In response to the ambiguity of the results among these studies, Fowler et al. (1987) suggested that many different factors could influence the performance results of studies on hypoxia. These include the interindividual variability of personality traits, motivation, and attentiveness. This is not to mention the variability of a subject's hypoxic response that modulates the SaO_2 and, presumably, performance. If the task has been learned well before the hypoxic exposure, it appears the oxygen depravation must be greater than that induced by breathing air at 10,000 to 12,000 ft in order for there to be a significant decrement in performance.

Effects of Exercise

Outside of cognitive effects, altitude profoundly affects both maximal and submaximal exercise performance. A review by Fulco et al. (1998) concluded that the magnitude of submaximal exercise impairment is proportional to both the elevation and exercise duration, at a given altitude, and that submaximal exercise performance can improve with continued exposure without an increase in VO_2max. VO_2max progressively declines with increasing elevation and thus the relative difficulty of exercising at a specific submaximal power output progressively increases.

As previously discussed, breathing air at altitudes below 10,000 ft does not normally produce symptoms and signs of hypoxia in individuals at rest. However, even mild exercise can produce dyspnea, a reduction in physical work capacity, and impairment in performance of skilled tasks (Ernsting, 1984). Due to the metabolic demand of the exercising muscles, SaO_2 will drop dramatically in individuals exercising at altitude. This will effectively raise the perceived altitude and potentially decrease performance even further.

COGNITIVE ASSESSMENT

Introduction

There is no proven method to quantitatively assess cognitive performance. In the past, difference techniques were used to evaluate cognitive performance, for example: visual impairment, code tasks and conceptual reasoning, memory, and what is traditionally labeled as "cognitive performance" (historically assessed using several tasks including addition, map compass, and computer interaction). Cognitive performance is usually more affected by altitude than psychomotor performance, and it has been suggested that complex tasks are typically affected before simple tasks (Cudaback, 1984; Kennedy et al., 1989). Impaired performance can manifest itself in increased errors, slowing of performance, or a combination of these factors.

A variety of assessment tools have been employed to assess cognitive performance. Two broad categories of testing exist based on the nature of the test (Alluisi, 1967). The first means of testing involves full-scale simulations. This provides maximum face validity (judgement regarding the appropriateness of use of the instrument in a given assessment situation through the process of simple inspection of the

instrument) and involves operators in situations that closely resemble the operational situations in which they would normally be found. Unfortunately, apart from the economic costs of such testing, there are two other important disadvantages to this sort of testing. First, it is difficult to assess the operator's performance (if it were possible, it might as well be done in an operational situation). Second, the more specific the simulation, the more difficult it is to generalize the results.

Specific-test techniques use a myriad of relatively abstract tests consisting of a number of appropriately selected individual tasks performed sequentially. Several common tasks include: simple reaction time task, where subjects must respond as quickly as possible to a given stimulus; code substitution tasks, involving converting a message into a coded one using a simple transfer code; and vigilance assessment, using relatively monotonous tasks which subjects must monitor for small changes over long periods of time. Performance can be assessed accurately and generalized to other situations in which similar tasks are used. The disadvantages, however, include a lack of face validity (similarity to real world task presentation) and little to no correlation between the test situation and the operation. Also, any given operational task generally occurs as a part of a complex task, the elements of which must be performed concurrently, with the interaction among the elements being the rule rather than the exception (Chiles, 1982).

Based on this information, several intermediate techniques for assessing performance have been developed to attempt to minimize the disadvantages of the previously mentioned techniques without loss of the advantages. These techniques provide operator performance that can be accurately assessed while at the same time yielding results that may be generalized to a variety of fields. The tasks are combined

into a multiple-task performance battery that has relatively high face validity in terms both of content and acceptance by operation personnel. The synthetic-work method is also advantageous because large investments in training time are not needed. It does not simulate any specific system of interest, which is both a weakness and a strength. It is a weakness because of problems in generalizing to specific systems, but it is a strength because subjects can be convinced to react to the device for what it is without comparing it to some other "real world" situation.

The two primary models for describing human information processing in applied contexts are the 'limited capacity' and 'multiple resources' models (Damos, 1998). The limited capacity model assumes that humans cannot process information from two or more sources (tasks) simultaneously because information from the sources must compete, either for some common processing mechanism or resource. Thus, according to this model, information cannot be processed in parallel. Support for this model has increased recently when investigators demonstrated an upper limit on the amount of information processed per second.

The multiple resources models have generally not addressed issues related to information overload directly. This model assumes parallel information processing where tasks requiring one set of resources can borrow other idle resources as the information processing load increases. Regardless of the model, operators respond with a variety of strategies to reduce high levels of information processing loads. Three of the most common are task shedding, processing delay, and use of alternate modalities. These appear to be conscious attempts by the operator to reduce the processing load.

Synthetic Work Task

A synthetic work task is designed to occupy a position between single cognitive tests of component abilities presented sequentially and "part" simulators requiring time-sharing of resources, where the cognitive components are usually inseparable. SYNWIN (Elsmore, 1991; Elsmore, 1994) requires dividing attention among four concurrent cognitive tasks involving short-term memory scanning, mental arithmetic, visual monitoring, and auditory vigilance and discrimination. Each of the subtasks is displayed simultaneously in one quadrant of the screen, and the subject responds to each by clicking on the mouse. A small window in the center of the screen displays a composite score, which the subject is instructed to maximize. Both the presentation of concurrent tasks and explicit assignment of outcomes for component task performance (based on points awarded) are characteristics of real work tasks that are commonly lacking in other computer-based tests of performance. A discussion of the description, background, reliability, validity, and sensitivity of several of the components as studied alone will be presented followed by a description of studies using SYNWIN.

The memory-scanning task briefly presents six randomly selected letters at the beginning of the test session (known as the "positive set"), which the subjects are to memorize. Thereafter, single probe letters are presented every 20 seconds, and the subject has 5 seconds to decide whether each is a member of the memory set or not, or if unable to do so, to look up the original list before responding. As summarized by Perez et al. (1987), this test is diagnostic of the process of selective retrieval and comparisons in short-term working memory. It may also reflect processes involved in the encoding of stimulus items, categorization, response selection, and response execution. The positive

set only includes six letters and is short enough to be stored within a person's immediate (short-term) memory span. Although reaction time is often measured when this task is performed alone, this is not as indicative of the underlying processes of memory retrieval in this task, as it is not the sole focus of the subject. Evidence of reliability of this task is controversial, based on the numerous manners and situations in which the test has been conducted. But, with great numbers of trials per memory set (as is used in SYNWIN), the reliability scores are high (generally greater than $r = 0.70$). The memory search task appears to be indicative of the diagnostic processes involved in retrieval and comparison of items in short-term working memory. This task is often used as a secondary task under dual task conditions, as it is thought to be sensitive to the memory load the subject is under while performing a separate, primary task.

The mental arithmetic task requires adding two, three-digit numbers and entering the answer by incrementing or decrementing each digit of a digital counter. Scratch pads are not allowed, and the subject has to hold intermediate sums in memory while being frequently interrupted to attend to other concurrent tasks. Tests of "number facility" have been employed in intelligence testing, psychopharmacology, behavioral toxicology, and as a technique for testing and developing theories of human memory (Perez et al., 1987). Solution of these problems involves retrieval of information from long-term memory (basic math facts), working memory capacity in the form of short-term storage (keeping track of carry and place information), and the execution of cognitive procedures. It has been found that in adults, simple addition is largely a memory retrieval process. They appear to rely on a stored systematic structure of knowledge and not on such procedures as counting. Errors in calculation can be attributed to the loss of intermediate solutions

and carry information. Thus, this test appears to tap both long-term memory and working memory capacity.

The latency data reflect the speed with which information is retrieved from long-term memory and working memory processing and storage, as well as distraction from other subcomponents. The reliability of the computer version of the test has not been performed; however, a pencil and paper form of the test has been tested (Perez, 1987). Arithmetic performance showed improvement over the first nine days of testing and remained stable thereafter. The interday correlations for the task were relatively high (r = 0.935). This indicates that tests of simple addition will yield relatively stable performance over time. This test appears to measure the construct of numerical ability (as previously mentioned, tapping both long-term and working memory capacities). Based on research by several individuals, multi-digit addition problems requiring complex mental calculations are performed by a series of elementary stages. This test has been shown to be sensitive to a range of toxic, drug and environmental stressors. Some tests only showed significant decrements in performance when part of a dual-task condition. Mental addition has been shown to be sensitive to the effects of sleep deprivation and the physiological effects associated with underwater diving. The literature did not reveal that this test having ever been utilized in hypoxia studies.

The two monitoring tasks are representative of elements common to a number of watch-standing jobs. The visual monitoring task presents an indicator ranging from 100 to 0. The task is to prevent the indicator from reaching 0 by clicking on the meter. Points are awarded for each reset, with the number of points being proportional to the distance of the pointer from 100 at the time of reset up to a maximum of 10 points. If the

indicator reaches 0, the subject is penalized 10 points for each second it remains there. The auditory task presents either 931 Hz or 1234 Hz beeps every 5 seconds. The subject has up to 5 seconds to decide which tone occurred and then to click a button if it was the less frequent higher tone, which occurs with a probability of 0.2. Thus, the subject not only has to monitor the tones, but also discriminate between them prior to making a response. In general, performance on monitoring tasks is often the first to be affected by environmental conditions or drugs.

Points are earned for correct responses to the individual subtasks and subtracted for errors. Points are also subtracted for errors of omission (e.g. missed signals, or for having to look up, rather than recall, the target letters in the memory task). In general, subjects are highly motivated to do well on the task and continue to improve their overall performance during up to 250 minutes of exposure to the task (Elsmore, 1994). SYNWIN has been shown to be sensitive to the circadian cycle and to sleep deprivation. Little to no degradation in performance was observed in well-rested subjects exposed to noise, or to aircrews under high operational loads. A more recent study found that the composite score for SYNWIN was a sensitive measure of performance depending on the time of day, although not significantly different between several sleep groups in a sleep deprivation study (Balkin et al., 2000).

SELF-MONITORING

Notably, very little research has been conducted regarding subjects' estimation of their cognitive abilities at altitude. Questionnaires such as the Environmental Symptoms Questionnaire (Sampsom et al., 1994) and the Borg scale (Borg, 1973) have been used to assess estimation of physical workload at altitude. It has been shown that altitude

adversely effects subjects' estimation of their exertion, even when quantitative measures of workload do not increase (Muza, 2000). Phillips et al. (1963) noted that performance under hypoxic conditions might depend on an interaction of several factors which includes the subject's ability to respond to awareness of physiological deficits by increased effort. Heath and Williams (1979) reported that although decision-making tends to be impaired at high altitude, it appears such impairment can be overcome by motivation and training. This assumes, however, that the subject is aware of the impairment and the need to increase effort to overcome it.

A recent investigation of self-monitoring of cognitive performance during sleep deprivation (Baranski and Pigeau, 1997), discusses several points that are also relevant in this study. During sleep deprivation, subjective reports of fatigue or sleepiness are correlated with cognitive performance decrements. Thus, the subjective estimate of how one feels can provide overt, preliminary indication that mental performances is (or may soon be) sub-optimal. However, extreme situational demands can lead to passive inattention, or active disregard of, the momentary subjective assessment of fatigue or sleepiness. In some situations, distinct environmental cues can provide the individual with explicit and fairly immediate feedback about their declining performance (e.g. momentary loss of vehicular control). Unfortunately, in many critical situations, feedback from the environment may not be available and thus the accurate assessment of one's own performance provides the only means by which to identify a potentially life-threatening state. As reported in this study, the relation between the pre-task evaluation and actual performance provides an index of how well individuals can anticipate a sleep-deprivation induced change in cognitive performance (prospective self-monitoring).

Conversely, the relation between the post-task evaluation and actual performance provides an index of how well individuals can detect a sleep-deprivation induced change in cognitive performance once it occurs (retrospective self-monitoring).

CHAPTER III

METHODS

PARTICIPANTS

Ten subjects (five male and five female) were selected on a volunteer basis from the Front Range region (~ 5,000 ft, P_B = 632.5 mm Hg) of Colorado. All subjects were between the ages of 18 and 60. Prior to data collection, each person signed an informed consent document (Appendix A) as approved by the Colorado State University Human Research Committee. Subjects completed an initial medical screening questionnaire (Appendix B) to reveal any possible medical risk factors that were subsequently reviewed by a physician. Subjects were screened to ensure that they had not traveled below 5,000 ft for the two weeks prior to testing. Subjects also completed a medical screening questionnaire (Appendix C) the day of each session prior to exposure.

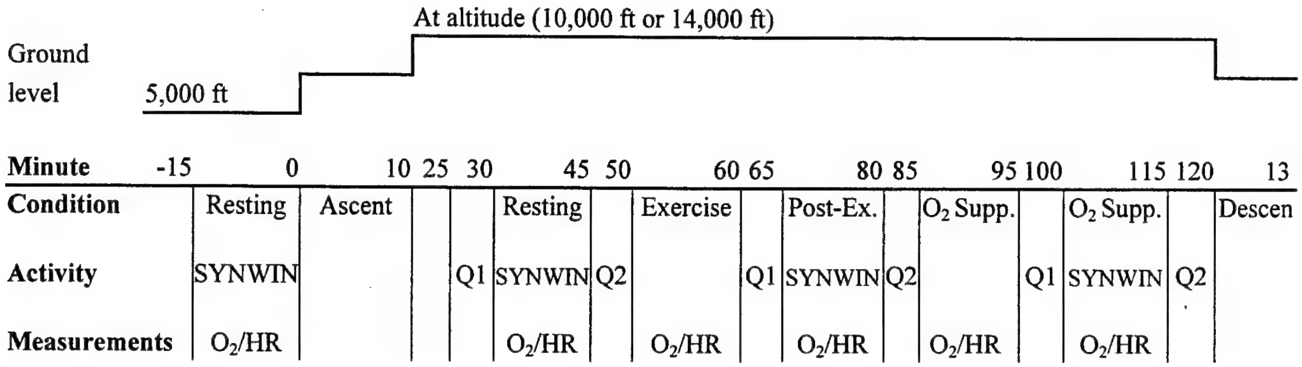
EXPOSURE PROFILES

To study the effect of mild hypoxia on actual and perceived cognitive abilities, subjects were exposed to two different hypobaric environmental conditions. Prior to any exposure in the hypobaric chamber, subjects practiced the cognitive test, SYNWIN (described in Chapter II), to minimize the learning curve during the study. While in the chamber, subjects were allowed to interact with each other and the test administrator to simulate the experience of a pilot and crew when on a mission.

Each exposure profile consisted of four sections. First, a 15-minute, ground-level (5,000 ft) test session of SYNWIN was completed. Subjects were then taken to either

10,000 ft (P_B = 522.7 mm Hg) or 14,000 ft (P_B = 447.0 mm Hg) in the hypobaric chamber during a 10-minute "ascent" period. After 15 minutes at "altitude", subjects completed a pre-test questionnaire to predict their performance on the next test session as compared to the previous session (in this case, the ground level session). Subjects then performed 15 minutes of SYNWIN. After finishing the test, subjects were asked to complete the post-test questionnaire to estimate his/her performance on the test (disregarding their previous assessment). This protocol for the test session of SYNWIN, preceded and followed by the questionnaires, was repeated for the remaining two "altitude" conditions.

To simulate the completion of some physical task at altitude, subjects performed 10 minutes of moderate exercise doing a step test (9.5 inches high at 25 steps/minute). Following this exercise bout, subjects repeated the 15-minute test session, as previously described. Each subject was then placed on 100% oxygen (via facemask) for 10 minutes (while still at altitude) to return them to a normoxic state. The final 15-minute test session was repeated while breathing O_2. Following completion of this test, O_2 was discontinued and a 10-minute "descent" to ground level completed the exposure. A time scale of an exposure is shown.



SYNWIN: SYNWIN test administered
Q1: Pre-test estimation questionnaire
Q2: Post-test estimation questionnaire
O_2: O_2 saturation measurement
HR: Heart rate measurement

During all test sessions, and for the duration of the exposure, subjects' arterial O_2 saturation (SaO_2) and heart rate (HR) were recorded every five minutes using a non-invasive fingertip pulse oximeter (Ohmeda, Biox III, Boulder, CO). The real time results were not shared with the subject, as it would have biased the subject as to his/her level of cognitive ability. Each subject completed two exposure profiles (a maximum of three hours) on two separate days separated by at least 48 hours. Volunteers were briefed on the test conditions prior to each exposure and debriefed at the end of the study.

The hypobaric exposure to 14,000 ft was chosen in order to reflect the FAA's maximum allowable altitude for private pilots, as well as the approximate altitude which many amateur mountaineers (and potential rescue missions) attempt to summit in the continental United States. This exposure level is well below the lowest altitude associated with the occurrence of decompression sickness at 21,200 ft (Webb et al., 1998). The 10,000 ft exposure was chosen to reflect typical flight profiles for private pilots and is below the level requiring O_2 supplementation by the FAA. This level lies in

the controversial range regarding whether cognitive hypoxic effects can even be detected. A hypobaric chamber (33 ft long by 10 ft diameter) was used to simulate the 10,000 ft and 14,000 ft altitudes. An approved Standard Operating Procedure for use of the Colorado State University Hypo-Hyperbaric Chamber was followed. All testing and training occurred inside the chamber to maintain the same testing conditions among test sets. Ascent and descent rates were less than 1,000 ft per minute, well below the maximum allowable rate of 5,000 ft per minute described in U.S. Air Force Instruction (AFI) 11-403.

Safety Precautions

A test administrator was present inside the chamber during all exposures. He/she was trained to recognize and respond to any emergencies that might arise inside the chamber while at altitude. An emergency checklist was available inside the chamber and communication was maintained with the outside supervisor at all times. The test administrator was responsible for administering all the test sets, observing the general status of the subjects, and recording relevant data.

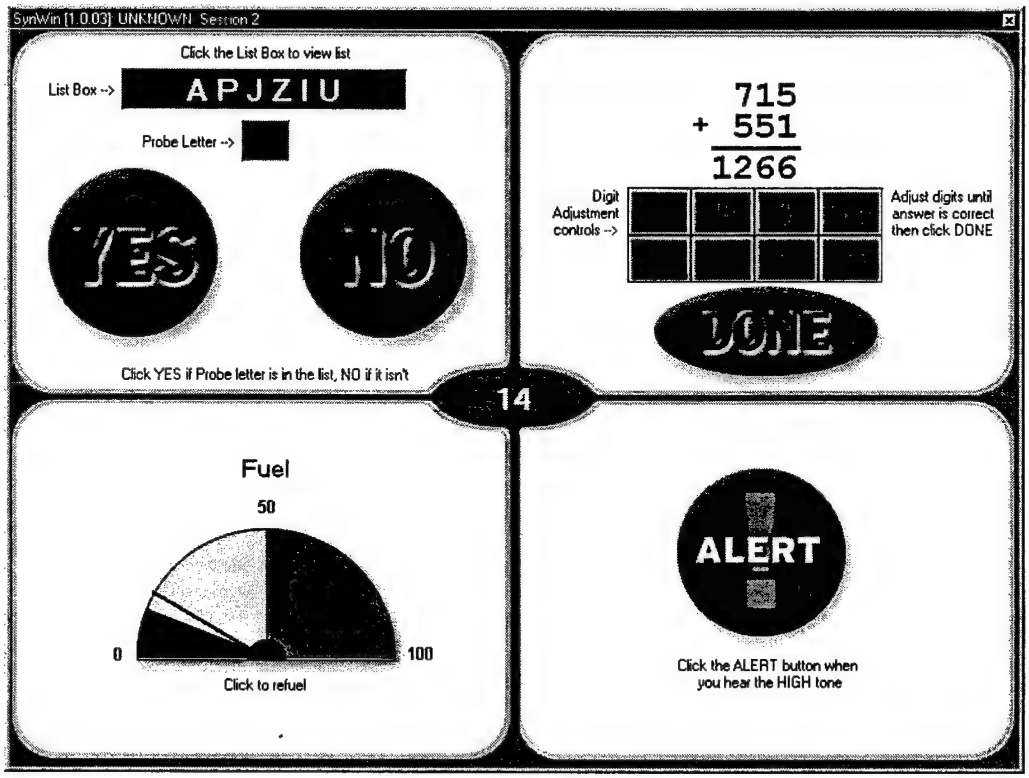
COGNITIVE TEST

Each of the subjects completed SYNWIN during each exposure as described above. SYNWIN was presented using notebook computers. Dr. James Miller, U.S. Air Force Research Laboratory, Brooks AFB, Texas provided the software for SYNWIN.

SYNWIN is a complex task that test subjects' ability to do several things at once. There are 4 subcomponents within the task. Points are awarded for correct responses and deducted for errors. The point total appears in a small box in the center of the screen. A high-pitched "squeak" sounds for correct responses, and a "burping" sound occurs after

errors. Each task is presented in one of 4 "windows" on the screen and the objective is to earn as many points as possible.

The following screen was presented to subjects during each testing session. Written instructions, similar to the following description of each task, were provided prior to the practice session.



Upper left window: Memory Task

This task required memorization of a list of letters that was displayed in the top box for 5 seconds at the beginning of the session. During the session, probe letters appeared in the center box. The task was to click on the "YES" or "NO" box as quickly as possible after the letter appeared to indicate whether or not the letter was one of the letters from the list. 10 points were awarded for each correct response, and a penalty of 10 points occurred for each error. Clicking on the list box revealed the letter (if forgotten) at a penalty of 5 points.

Upper right window: Arithmetic task

This arithmetic task required mental addition of two 3-digit numbers. The answer was recorded by clicking on the "+" and "-" boxes below each digit of the answer. The "+" box increased the digit by one, and the "-" box decreased the digit by one. For example, to set a digit to 8, a subject could either click on the "+" box 8 times, or on the "-" box twice. 20 points were earned for each correct answer, and 10 points deducted for each error.

Lower left window: Meter monitoring task

This task presented an indicator that moved from 100 to 0. The task was to prevent it from reaching 0. This was accomplished by clicking on the meter. Points were awarded for each reset, with the number of points being proportional to the distance of the pointer from 100 at the time of reset up to a maximum of 10 points. If the indicator reached the "red zone", 10 points were deducted for each second it remained there while an auditory warning warned of the deductions.

Lower right window: Auditory detection task

For this task, a tone beeped every 5 seconds through headphones the subject was wearing. Occasionally, the tone was higher than usual. When this happened, 10 points were earned for clicking on the "ALERT" box. There was no penalty for failing to report a high tone. False clicks resulted in a penalty of 10 points.

ESTIMATION QUESTIONNAIRES

Prior to each test session at altitude, each subject rated how he or she believed they would perform on the next session compared to the previous session by completing the Pre-Test Abilities Estimation Questionnaire (Appendix D). Following the test

session, each subject completed the Post-Test Abilities Estimation Questionnaire (Appendix E) rating how well he or she perceived they had performed compared to the previous session.

DESIGN

Several independent variables were investigated in this study to include altitude, exercise, oxygen supplementation and learning effects on the primary dependent variable, cognitive performance. As described previously, four tests were conducted at two altitudes (10,000 ft and 14,000 ft) t0 (ground level), t1 (resting at altitude), t2 (post-exercise at altitude), and t3 (resting with oxygen supplementation at altitude). The test sessions were designed to evaluate the effect of the environmental conditions mentioned above in the following manner. First, the potential difference in cognitive performance between ground level and altitude (t0 vs. t1), and potentially between the two different altitudes, was evaluated. Secondly, performance before and after exercise at the two different altitudes was examined (t1 vs. t2). And finally, the effect of oxygen supplementation at altitude was investigated by comparing the scores while resting at altitude with those at rest during oxygen supplementation (t1 vs. t3). Depending on the results of the learning effect, order could be involved in all analyses. In all evaluations, the five scores reported on each test session (composite score, and the four subcomponents of the test: memory, math, visual monitoring and auditory monitoring) were the dependent variable investigated.

The estimation data included the actual data that was transformed to yield the difference in raw scores between the three altitude sessions and the previous test sessions (t1-t0, t2-t1, and t3-t2), and the corresponding estimations of performance rated on a five-

point scale. The correlations between the subjective rating of performance (questionnaires) and the actual difference in scores were evaluated for each test session.

All statistical analyses were performed using PC-based statistical programs (SPSS INC., Chicago, IL). Raw data as collected during the study are reported in Appendices F and G. To determine if order should be examined throughout the analysis, a *t*-test for order effects for all dependent, cognitive variables was conducted on the ground level data (t0). Second, to evaluate the altitude variable on performance as compared to ground level, a single-factor repeated measures analysis of variance (ANOVA) with three levels, ground, 10,000 ft and 14,000 ft (after finding no significant difference between ground level sessions, the results were average to yield one ground level value to balance the analysis) was performed. A two by two factor ANOVA with repeated measures on both factors was performed to evaluate changes performance at altitude with exercise. The two levels of altitude were 10,000 ft and 14,000 ft. The two levels of exercise were pre-exercise (t1) and post-exercise (t2). A second two by two factor ANOVA with repeated measures on both factors was performed to evaluate changes in performance at altitude with oxygen supplementation. The two levels of altitude were 10,000 ft and 14,000 ft and the two level of oxygen were no supplemental oxygen (t1) and supplemental oxygen (t3). For the estimation data, tests of the relationship between the differences in performance and the pre- and post-test assessments were performed using the Spearman Correlation method. Only significant effects will be discussed.

CHAPTER IV

RESULTS

SUBJECTS

Ten male and female subjects (n=10), ranging in age from 22-53 years, participated in this study (Table 2). All subjects passed both of the medical screening questionnaires prior to participation in the study.

TABLE 2. Subject Characteristics (mean ± standard error)

		Average	Std. Error	Min	Max
Male					
Number	5				
Age (yrs)		36.2	3.3	25	53
Weight (kg)		77.0	3.2	65.9	88.6
Female					
Number	5				
Age (yrs)		28.2	2.9	23	38
Weight (kg)		61.4	4.0	54.5	66.8
Overall					
Number	10				
Age (yrs)		32.2	2.9	23	53
Weight (kg)		69.2	3.6	54.5	88.6

ORDER EFFECT

The altitude of the first exposure was randomized among subjects to allow for the investigation of a learning effect (order) as well as the altitude effect (Table 3).

TABLE 3. Exposure Order

Subject #	Gender	Exposure 1	Exposure 2
1	F	10	14
2	F	10	14
3	M	14	10
4	F	14	10
5	M	14	10
6	M	10	14
7	M	10	14
8	F	14	10
9	M	14	10
10	F	10	14

Upon examination of the ground level data, however, there was no statistically significant difference for any variable based on order. Based on this information, order was not considered in further analyses. It was assumed that if an order effect did not appear at ground level, further examination for this effect at altitude would inappropriately increase the probability of finding one based on chance.

ALTITUDE EFFECT

All means and standard errors from the ANOVA of the performance data at ground level, and the two trials at altitude under resting conditions, can be found in Table 4. The results of the analysis, as well as the values for the Tukey post-hoc test to determine which results were significantly different, if required, are listed in Table 5. Overall performance (composite scores) under resting conditions (t0 vs. t1) was significantly greater at 10,000 ft than both the 14,000 ft and 5,000 ft conditions. There was no significant difference in overall performance (at rest) between 14,000 ft and 5,000 ft. The same results were true for the memory scores. The math score analysis was the only one that violated Mauchly's Test of Sphericity. For this reason, the Greenhouse-

Geiser analysis was used, with the corresponding lesser degrees of freedom. There was still a significant effect, with greater scores at 10,000 ft compared to 14,000 ft.

TABLE 4. Cognitive Performance and Low and High Altitudes

	Ground level (5,000 ft)		10,000 ft		14,000 ft	
Variable	Mean	Std. Error	Mean	Std. Error	Mean	Std. Error
Composite	870.25	68.498	997.10[1,2]	79.840	861.30	69.875
Memory	217.70	16.747	255.70[1,2]	6.878	215.90	15.260
Math	439.95	64.549	520.00	78.061	426.70	65.956
Visual Monitoring	121.85	1.938	121.50	2.531	121.40	1.759
Auditory Monitoring	90.40	2.367	99.00	2.376	97.40	6.433

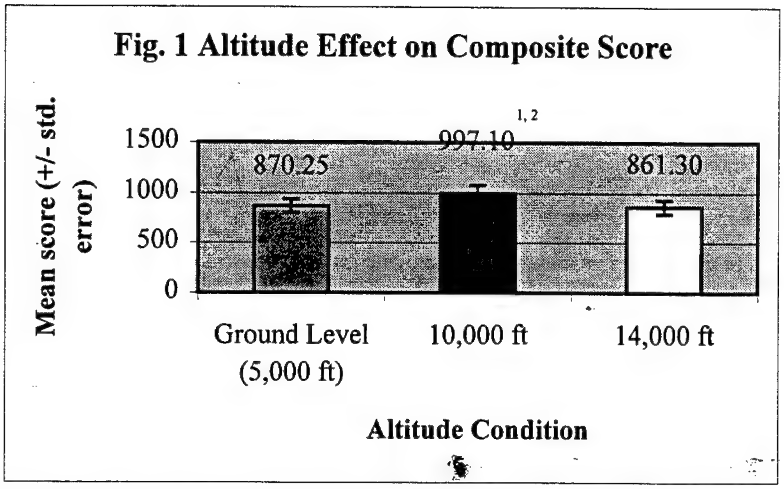
[1] Variable significantly ($p<0.05$) greater than 14,000 ft
[2] Variable significantly ($p<0.05$) greater than 5,000 ft

TABLE 5. ANOVA of Altitude and Ground Level at Rest

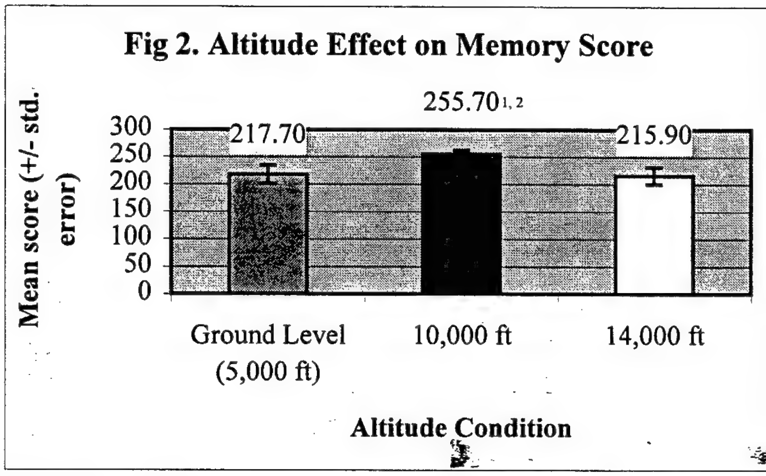
			Tukey Post-hoc test (if significant)			
Variable	F-value	significance	Critical Value	Ground-10,000 ft diff	Ground-14,000 ft diff	10,000-14,000 ft diff
Composite	7.199	0.005	102.19	126.85*	8.95	135.8*
Memory	5.126	0.017	35.83	38.00*	1.80	39.80*
Math	4.467	0.049	91.35	80.05	13.25	93.90*
Visual	0.014	0.986				
Auditory	1.224	0.317				

* Significant difference between altitudes listed above

The following figures depict the significant findings from the above analysis of the effects of altitude by examining the resting condition at ground level and at altitude.

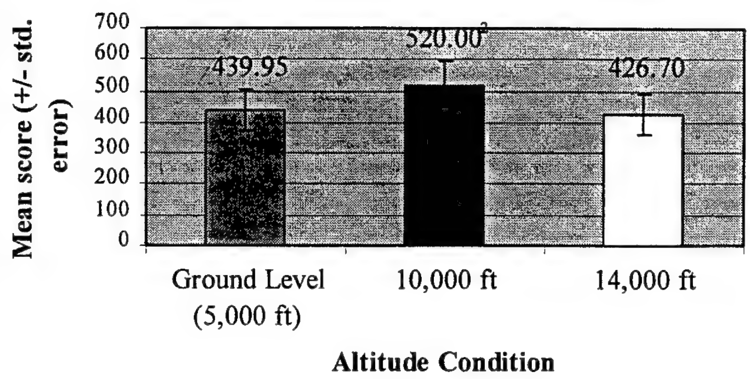


[1] Variable significantly ($p<0.05$) greater than ground level
[2] Variable significantly ($p<0.05$) greater than 14,000 ft



[1] Variable significantly ($p<0.05$) greater than ground level
[2] Variable significantly ($p<0.05$) greater than 14,000 ft

Fig. 3 Altitude Effect on Math Score



[2] Variable significantly ($p<0.05$) greater than 14,000 ft

EXERCISE AND ALTITUDE EFFECT

There were significant changes in cognitive performance following exercise at altitude. The means and standard errors from the ANOVA can be found in Table 6. The results of the ANOVA are shown in Table 7. There were several significant differences in performance based on both exercise and altitude (in an evaluation of t1 and t2) although no interactions were observed between the two variables. Post-exercise (t2) performance was significantly greater than pre-exercise performance as seen in increased composite scores, as well as the math and auditory monitoring scores. A similar altitude effect was seen in this comparison of trials as that shown under the resting condition. The mean composite score from the two test sessions under investigation (t1 and t2) at 10,000 ft, regardless of exercise condition, was greater than the mean at 14,000 ft. A similar altitude effect was also seen for the memory score. Without any significant interactions between exercise and altitude, however, it was impossible to separate t1 and t2 from each of the altitude conditions.

TABLE 6. Cognitive Performance after Exercise at Altitude

Variable	Exercise: Pre-exercise (t1) Mean	Pre-exercise (t1) Std. Error	Exercise: Post-exercise (t2) Mean	Post-exercise (t2) Std. Error	Altitude: 10,000 ft Mean	10,000 ft Std. Error	Altitude: 14,000 ft Mean	14,000 ft Std. Error
Composite	929.20	70.86	980.35*	73.138	1003.00	75.53	906.50*	73.99
Memory	235.80	10.29	226.55	14.512	244.05	9.66	218.30*	16.18
Math	473.35	68.79	506.55*	67.327	517.85	71.57	462.05	68.12
Visual	121.45	1.51	123.80	2.544	122.50	2.23	122.75	1.81
Auditory	98.20	3.52	125.50*	3.420	117.60	3.51	106.10	5.03

* Significant difference between means (p<0.05)

TABLE 7. ANOVA of Pre- and Post- Exercise at Altitude Effects

Variable	Exercise: F-value	Exercise: significance	Altitude: F-value	Altitude: significance
Composite	12.593	0.006*	5.108	0.050*
Memory	1.753	0.218	5.244	0.048*
Math	13.781	0.005*	2.893	0.123
Visual	0.943	0.357	0.013	0.913
Auditory	52.379	<0.001*	3.205	0.107

* Significant difference between means (p<0.05)

The following figures summarize the statistically significant results.

Fig. 4 Exercise Improves Composite Score

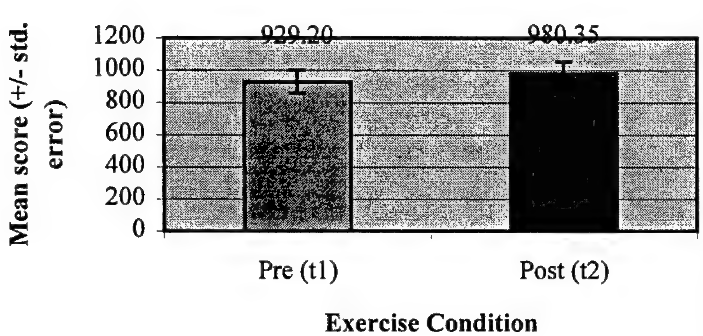


Fig. 5 Exercise Improves Math Score

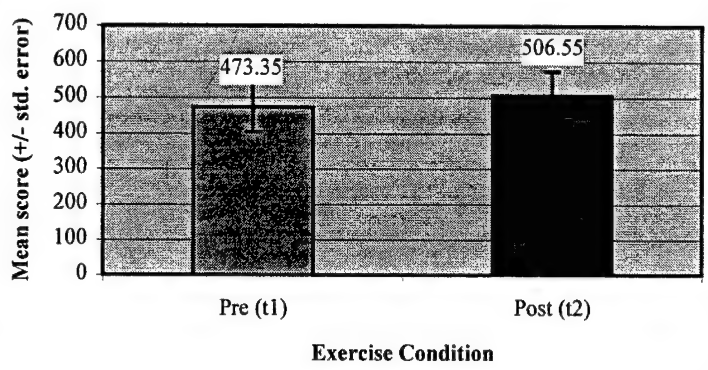


Fig. 6 Exercise Improves Auditory Monitoring Score

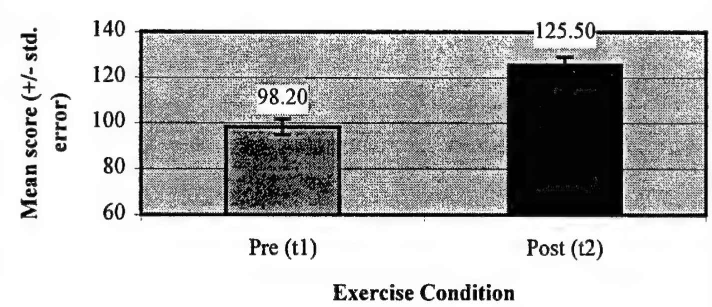


Fig. 7 Composite Score (t1 and t2) Lower at 14,000 ft than 10,000 ft

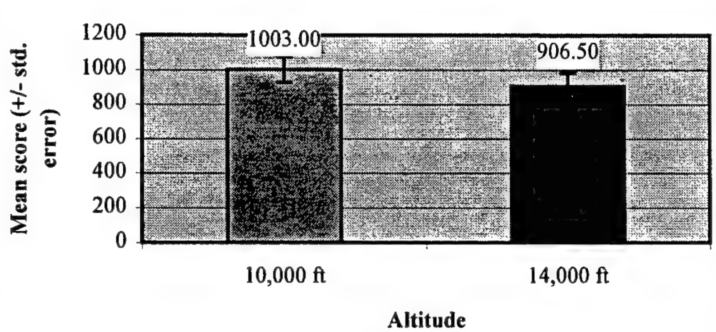
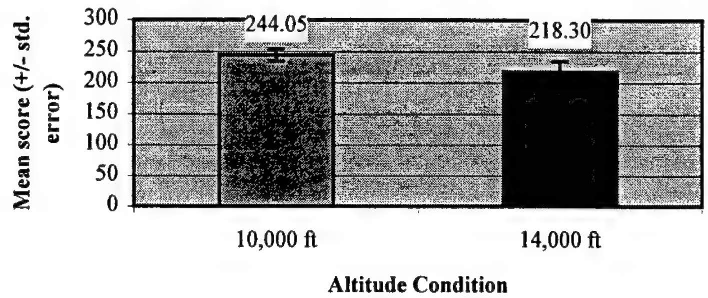


Fig. 9 Memory Score (t1 and t2) Lower at 14,000 ft than 10,000 ft



OXYGEN AND ALTITUDE EFFECT

There was a significant difference in several variables based on the oxygen supplementation condition as well as altitude. The means and standard errors from the ANOVA are listed in Table 8. The results of the analysis are shown in Table 9. The results of oxygen supplementation were similar to those from exercise. Oxygen supplementation significantly increased the math and auditory performance, regardless of altitude. Although not significant, these two variables contributed to a trend of increased composite performance. Once again, the mean composite and math scores (from t1 and t3) were significantly greater at 10,000 ft compared to 14,000 ft. There were no significant interactions between oxygen supplementation and altitude prohibiting further investigation into altitude by exercise (test session) effects.

TABLE 8. Cognitive Performance during Oxygen Supplementation at Altitude

	Oxygen				Altitude			
Variable	Without O_2 (t1)		With O_2 (t3)		10,000 ft		14,000 ft	
	Mean	Std. Error	Mean	Std. Error	Mean	Std. Error	Mean	Std. Error
Composite	929.20	70.860	993.65	85.753	1014.35	82.592	908.50*	78.320
Memory	235.80	10.286	234.25	11.862	247.70	8.634	222.35*	13.286
Math	473.35	68.789	520.20*	77.462	538.20	80.892	455.35	69.871
Visual	121.45	1.505	120.85	2.935	119.75	3.321	122.55	1.517
Auditory	98.20	3.522	118.45*	5.884	108.25	3.249	108.40	7.704

* Significant difference between means ($p<0.05$)

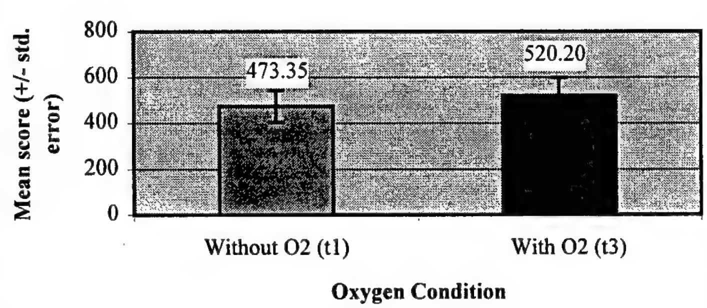
TABLE 9. ANOVA of Oxygen and Altitude Effects

	Oxygen		Altitude	
Variable	F-value	significance	F-value	significance
Composite	4.768	0.057	5.512	0.043*
Memory	0.032	0.862	7.635	0.022*
Math	5.338	0.046*	3.818	0.082
Visual	0.042	0.841	0.586	0.464
Auditory	29.068	<.001*	<.001	0.985

* Significant difference between means ($p<0.05$)

The following figures summarize the statistically significant results.

Fig. 10 Oxygen Supplementation Improves Math Scores



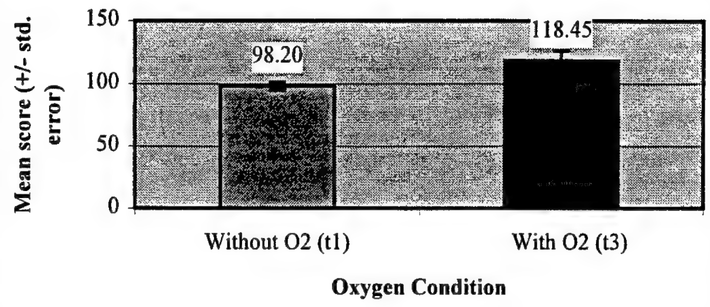


Fig. 11 Oxygen Supplementation Improves Auditory Monitoring Scores

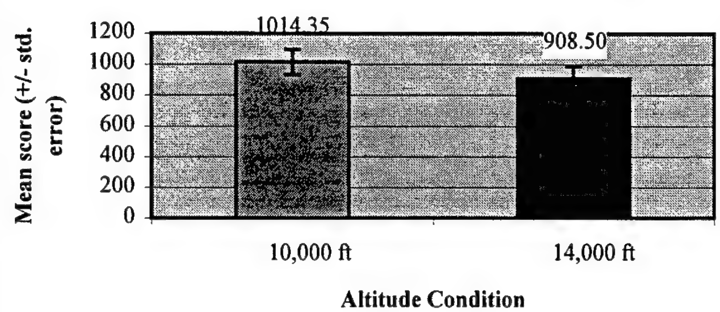


Fig 12. Composite Score (t1 and t3) Lower at 14,000 ft Compared to 10,000 ft

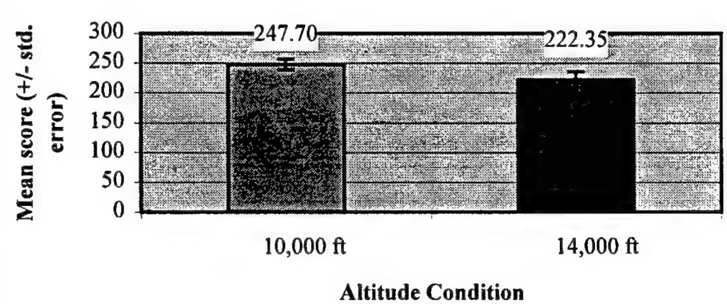


Fig. 13 Math Score (t1 and t3) Lower at 14,000 ft Compared to 10,000 ft

ARTERIAL O_2 SATURATION AND COGNITIVE PERFORMANCE

Although arterial O_2 saturation levels and heart rate were recorded during all test sessions (Table 10), these data were not analyzed. Inspection of the raw data reveals that there were no overlaps in O_2 saturation between altitudes except under oxygen supplementation. Thus, further inquiry would just repeat information already examined through differences in altitudes.

TABLE 10. Average O_2 Saturation and Heart Rate by Altitude and Trial

	O_2 Saturation								Heart Rate							
	10,000 ft				14,000 ft				10,000 ft				14,000 ft			
Subject	t0	t1	t2	t3	t0	t1	t2	t3	t0	t1	t2	t3	t0	t1	t2	t3
1	98	92	92	100	96	90	86	99	71	75	86	73	71	84	103	88
2	98	96	93	98	96	90	90	99	78	81	104	87	76	85	105	86
3	97	93	95	99	96	86	86	97	73	60	61	56	70	79	86	73
4	99	94	93	100	97	88	87	99	67	67	75	60	73	75	89	69
5	96	91	91	99	96	84	84	98	80	67	83	75	81	79	92	83
6	97	92	93	100	97	79	85	99	51	51	54	50	51	57	73	52
7	94	92	90	99	95	87	84	99	70	69	83	69	79	73	83	68
8	98	93	93	98	98	86	86	97	55	55	59	57	64	66	75	68
9	99	91	90	98	99	84	83	98	74	71	76	72	70	70	79	72
10	97	91	93	98	97	87	86	98	85	83	102	86	72	78	98	80

PERFORMANCE DIFFERENCE AND ESTIMATION

Due to the small sample size and lack of normal distribution for the estimation questionnaire data, the Spearman correlation was selected to make statistical correlations. The correlation coefficients, between the actual difference in scores and the pre- and post-test estimates, for each altitude are shown in Table 11. There was only one significant correlation between the pre-test estimate and performance occurring for the math test at 14,000 ft during oxygen supplementation. There were several significant correlations between the actual difference in performance and the post-test estimates to

include, at 10,000 ft: composite and memory scores after the resting condition (t1), composite scores after exercise (t2); and at 14,000 ft: composite and math scores after rest (t1), and composite, memory, and auditory monitoring scores after oxygen supplementation (t3). There were several significant correlations between the pre-test and post-test questionnaires to include, at 10,000 ft: composite and memory estimations after exercise (t2), and auditory monitoring during oxygen supplementation (t3); and at 14,000 ft: composite, memory, and math scores after rest (t1), and visual and auditory monitoring scores after exercise (t2).

TABLE 11. Correlation Coefficients between Performance and Estimations

	10,000 ft						14,000 ft					
	Pre-test estimate			Post-test estimate			Pre-test estimate			Post-test estimate		
Actual Difference	t1	t2	t3	t1	t2	t3	t1	t2	t3	t1	t2	t3
Composite	-0.080	0.157	-0.570	0.822*	0.784*	-0.474	0.271	-0.225	0.213	0.682*	0.182	0.817*
Memory	0.208	-0.020	0.070	0.898*	0.388	0.386	0.037	0.501	0.250	0.132	-0.482	0.824*
Math	-0.424	0.192	-0.107	0.509	0.485	0.558	0.541	0.346	0.726*	0.751*	0.202	0.475
Visual	0.273	0.085	-0.073	0.285	0.539	0.268	-0.263	0.290	-0.229	0.541	0.187	0.572
Auditory	0.571	0.378	-0.428	0.283	-0.220	-0.240	0.149	0.281	0.421	<.001	-0.240	0.883*
Pre-test estimate												
Composite				-0.022	0.646*	-0.289				0.724*	-0.401	<0.001
Memory				0.268	0.760*	0.298				0.755*	-0.008	0.299
Math				0.129	-0.124	0.496				0.691*	-0.542	0.604
Visual				0.185	-0.072	0.102				-0.046	0.645*	0.356
Auditory				0.199	0.313	0.773*				0.089	0.733*	0.567

As one of the hypotheses of the study was that subjects might be prone to over-prediction at altitude, a system was devised to rate predictions that were not significant in correlation analysis. By observing the raw data, cutoff scores were chosen for each variable where certain estimation ratings should have occurred. For example, for both the composite scores and the math scores, the cutoff of +/- 60 was chosen as the scores that a subject should have rated a corresponding +/- 1 estimation questionnaire score.

Actual scores falling within this range should have been rated a zero. To allow for a range, however, subject's ratings were counted correct if they had the correct sign (i.e. if the actual score was +30, and the subject had either a 0 or +1 rating, this was counted correct). Under and over predictions were assigned to estimation ratings that did not correspond to the determined ranges as shown below.

Composite

Actual Score	-200	-60	0	60	200
Estimation Rating	-2	-1	0	1	2

Memory

Actual Score	-100	-40	0	40	100
Estimation Rating	-2	-1	0	1	2

Math

Actual Score	-200	-60	0	60	200
Estimation Rating	-2	-1	0	1	2

Visual

Actual Score	-40	-10	0	10	40
Estimation Rating	-2	-1	0	1	2

Auditory

Actual Score	-70	-30	0	30	70
Estimation Rating	-2	-1	0	1	2

The number of under and over predictions as found by the method stated above are listed in Table 12. Results for 10,000 ft and 14,000 ft tend to be similar in this regard. For this reason, both altitudes will be discussed together. For the pre-test estimations, at both t1 and t2, under prediction was common (thus subjects were estimating that there performance would be worse than it really was). The pre-test estimations at t3 tended to be over-predictions. The post-test estimates generally followed the same trend as the pre-test estimates, however, there were less variables that were so remarkably one-sided in either under or over prediction.

TABLE 12. Under (-) and Over (+) Prediction for Non-significant Correlations

	10,000 ft												14,000 ft											
	Pre-test estimate						Post-test estimate						Pre-test estimate						Post-test estimate					
	t1		t2		t3		t1		t2		t3		t1		t2		t3		t1		t2		t3	
	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+
Composite	5	1	3	1	2	5					1	2	6	1	6	1	2	4			6	0		
Memory	2	0	1	2	1	1			0	2	3	0	6	0	1	1	0	3	2	2	1	4		
Math	5	1	6	2	1	3	3	0	3	3	2	1	3	0	4	2					2	2	2	1
Visual	3	1	2	1	0	3	1	2	1	0	1	2	2	2	1	1	1	3	0	0	1	1	0	2
Auditory	2	0	4	0	3	4	1	0	5	1	3	4	4	0	5	1	0	5	4	0	5	0		

Trend towards under prediction

Trend towards over prediction

OTHER VARIABLES

There were several other sets of data collected during the test sessions that were not analyzed. Due to the relatively small sample size the chance that a Type I error would occur increased with increasing analyses. To minimize this, only the descriptive data of the following variables will be reported (Table 13).

TABLE 13. Other Variables (mean from 10 subjects)

Variable	t0	10,000 ft t1	10,000 ft t2	10,000 ft t3	t0	14,000 ft t1	14,000 ft t2	14,000 ft t3
Memory								
Dwell Time	31	32	34	32	36	34	33	34
% Correct	88	92	89	92	81	80	80	82
Math								
Dwell Time	193	196	189	192	186	193	193	190
% Correct	87	90	87	88	89	87	90	88
Visual Monitoring								
# Lapses	0	0	0	0	0	0	0	0
Auditory Monitoring								
# Lapses	1	1	1	1	0	1	0	1

Although these values were not statistically analyzed, the most notable observation was the lower percent correct on the memory task at 14,000 ft compared to 10,000 ft. Both scores stay at approximately the same level as the ground level (5,000 ft) run. However, no statistical difference was found between the scores at each ground level run in previous analyses.

CHAPTER V

DISCUSSION

ORDER EFFECTS

Prior to the evaluation of any of the data, an examination of a potential learning (order) effect had to be assessed. As previously discussed, an examination of the ground level data revealed no significant order effect for any variable. This was surprising considering Elsmore (1994) reported increased performance on the task for up to four hours. Due to time constraints, a four-hour training session was not feasible, although all subjects were given a 30 to 45 minute practice session prior to the beginning of the first test session. The lack of order effect could mean one of two things. First, since the task is composed of subcomponents that are relatively simple and commonly performed by most of the population apart from this task, the given training session could have been enough to eliminate a.significant learning effect for the duration of the study. However, there is also a second explanation resulting from the relatively small sample size. Due to the small sample size, the standard deviation for all of the measured variables was quite large. This could potentially negate an effort to distinguish a difference in means based on the experience level of the subject. Regardless of the cause, however, without a finding of order at ground level, this variable was considered negligible and not considered in any further analyses.

ALTITUDE EFFECT

Several unpredicted results were found in the analysis of both the actual cognitive performance data as well as the perception data. Regarding the performance data, it is notable that overall performance under resting conditions (t0 vs. t1) was significantly greater at 10,000 ft than both the 14,000 ft and ground level conditions. Although it seems reasonable for performance at 10,000 ft to be better than that at 14,000 ft, in light of virtually the same increase from ground level performance this result is unanticipated. Further evidence that altitude is not affecting performance (at least under resting conditions) was the similarity in mean scores between performances at 14,000 ft with those at ground level. Both the memory and math scores showed similar results as the composite score. It is reasonable that since the effect is seen in the composite score, the two primary components that contribute most to the score show the same trend. Although an evaluation of the raw data to try to determine the cause of this interesting result was completed, no further explanation was revealed.

One approach towards explaining the peak in performance at 10,000 ft deals with motivation. It is possible that as subjects knew when they were at altitude, they put more effort into the performance (potentially to overcome anticipated hypoxic effects) thus yielding greater scores than at ground level. Although they could still show the increased motivation at 14,000 ft, perhaps the motivation factor was negated by real decrements in performance caused by hypoxia under this condition. This is just one hypothesis and further investigation is necessary to uncover the basis of this effect.

EXERCISE AND ALTITUDE

As previously mentioned, exercise had a significant effect on the composite score, math score, and auditory monitoring score. However, the effect was opposite that which was originally anticipated. It was hypothesized that the lowering of arterial O2 saturation during exercise (which was observed) would lead to a decrement in performance following the exercise. This was not the case. All three variables showed increased means after exercise than before. A likely explanation for this is that exercise made the subjects more alert resulting in increased performance.

This is reasonable based on the two variables, math and auditory monitoring, which showed improvement, along with the distinction that the task was completed *post*-exercise and not *during* exercise. There is no ceiling on the maximum score on the math component, as the faster a subject completes the problems the more problems they will be able to accomplish in the given time period. The increased score could also be attributed to higher accuracy resulting in a greater score, or some combination of the two. As no penalty was assigned to the auditory monitoring, it is reasonable to conclude that it is the last priority of a subject. Thus increased alertness following exercise could make them more aware of signals that they had previously missed. As shown by the average heart rates in Table 9, cardiac output was still elevated at the time of the post-exercise test. However, increased oxygen demands of the muscles were no longer present. This could result in more oxygen being delivered to the brain and that presumably could be responsible for the noted improvements.

A similar altitude effect as that shown under resting conditions also appeared in this comparison of test sessions. The mean composite score from the two test sessions

under investigation at 10,000 ft, regardless of exercise condition, was greater than the mean at 14,000 ft. Ignoring the previous comparison to ground level, one possible explanation of this effect is that altitude is playing a role in decreasing scores at 14,000 ft, as previously discussed in the resting condition. On the other hand, given the similar values between ground level and 14,000 ft at rest (and a similar mean between 14,000 ft here and the ground level means), it is also possible that for some reason the 10,000 ft condition improves performance rather than the 14,000 ft condition decreasing performance. The same altitude effect was seen in the memory scores as discussed for the composite scores.

OXYGEN AND ALTITUDE

The results of oxygen supplementation are similar to those from exercise. Oxygen supplementation significantly increased the math and auditory performance, and although not significant, these two variables contributed to a trend of increased composite performance. It seems logical that oxygen would enhance performance if subjects were being adversely affected by a lack of oxygen (hypoxia). The beneficial results of oxygen supplementation on performance, regardless of the altitude, are suggestive of this effect. Once again, we see that the mean composite and math scores are significantly greater at 10,000 ft compared to 14,000 ft between the two test sessions under investigation (t1 vs. t3).

O_2 SATURATION AND COGNITIVE PERFORMANCE

Although O_2 saturation levels were collected throughout the trials, no statistical analyses were performed using these values. It was determined that any results to be found would just be repeating the results found in the differences between altitudes.

Second, since the O2 saturation levels were restricted to a very small range (at a maximum 75% to 100%) while the scores varied across a large range, any potential correlations would be virtually meaningless.

PERFORMANCE DIFFERENCE AND ESTIMATION

The second goal of this study was to look at the effects of altitude on perception. Based on the correlation between the actual difference in performance and the pre- and post-test estimations of performance, there does not look to be an effect of altitude on perception. Obviously, subjects were not able to predict their performance with any degree of accuracy prior to taking the test. Although changes in performance did occur (as evidenced from the discussion of actual results) pre-test estimations did not reflect this.

Subjects were much better at assessing performance after taking the test as evidenced by significant correlations at both 10,000 ft and 14,000 ft. At both altitudes, composite score was the closest correlated with the post-task estimate, which is expected considering the subjects were received feedback on their performance in regards to their overall score. Although there is a degree of variability since each test session was composed of three, 5-minute sessions and the subject was asked the result of the average of the sessions, in general subjects should do well on this estimation. Although several other variables show significant correlations with the post-test estimations during various trials (to include the memory, math, and auditory monitoring), the statistical significance of these finding should not be overemphasized. The larger the number of correlations performed, the greater the probability significant correlations will appear just based on chance. Without any obvious trends in the significant correlations, it is difficult to assign

much meaning to the ones that did appear significant other than that which has previously been discussed.

The pre-test/post-test correlation is not really meaningful in this case. Since there are not significant correlations between the pre-test estimations and the actual performance, it does not mean much to say that the pre-test and post-test estimations correlate. This is merely a function of the limited number of choices a subject could respond with (five categories for each estimation) as opposed to any practical validity.

By evaluating the estimations that did not significantly correlate with actual performance, it was possible to get some idea whether subjects were under or overestimating their performance in these areas. It is interesting that subjects tended to under predict their performance during both the resting (t1) and post-exercise (t2) conditions. This is potentially a result of the number of subjects who had some knowledge of the effects of altitude prior to participation in this study. It is estimated that at least seven out of ten of the subjects had foreknowledge of the effects of altitude on cognitive performance (as subjects were primarily physiology graduate students or pilots). Thus, it would make sense for them to predict worse performance at altitude before they had actually taken the test and gotten an idea of how they would do. This also helps explain the pre-test over prediction during oxygen supplementation (t3) when subjects may have anticipated more benefit from the oxygen than was actually present.

Post-test estimates also tended to error in the same direction as the pre-test estimates although there was more variability regarding the direction of error in estimation. Although under prediction still predominated for t1 and t2, there were more cases where the number of over predictions was close to the number of under-predictions.

This seems to indicate that as a group, subjects were unable to predict their performance on these variables (especially visual monitoring) with any degree of accuracy. The post-test estimations at 10,000 ft for t3 were the most random. Although there was a tendency to over predict (in all but the memory estimation), all of the variables for which this was true nearly as many under predictions as well. Possibly, as oxygen had less of a beneficial effect at 10,000 ft compared to 14,000 ft, subjects were less likely to feel marked physical improvements resulting in the scattering of estimations. At 14,000 ft, however, three of the post-test estimations correlated significantly with the actual differences in performance. All but two of the subjects had changes in actual performance of over 100 points during t3. With this large difference to report on, it is not surprising that subjects were able to rate their performance well after this.

OTHER VARIABLES

Although not analyzed statistically, the most notable observation of the other variables collected during the study was the lower percent correct on the memory task at 14,000 ft compared to 10,000 ft. At both altitudes, across trials the percent correct stay at approximately the same level as the ground level run (t0). Although no significant difference was found between the scores at each ground level run, the percent correct does appear to differ.

SUMMARY

In references to the specific aims of the study, the following conclusions can be made:

- Differences in actual cognitive performance under environmental conditions tested:
    - Ground level compared with 10,000 and 14,000 ft: Overall performance was

better at 10,000 ft than both 14,000 ft and ground level.

- The effects of exercise: Performance was improved after a short bout of exercise regardless of the altitude.

- The effect of oxygen supplementation: Performance was improved after 10 minutes of oxygen supplementation regardless of the altitude.

- Differences between perception and actual performance:

  - Subjects were not able to accurately predict performance prior to each test session, in general performance was under predicted at rest and post-exercise, and over predicted during oxygen supplementation (although actual performance was improved while on supplemental oxygen).

  - Post-test estimations of composite scores were well correlated with actual performance. Other variables had significant correlations with post-test estimations although there seemed to be no obvious trends to point to an explanation for this.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The intent of this study was to examine changes in perceived and actual cognitive performance under altitude conditions that would most closely reflect conditions private pilots might face. As such, the conclusions and future recommendations will be focused in that direction.

The continuing debate regarding the altitude at which cognitive performance becomes adversely affect may find merit from results found here. Under all test conditions, at rest, post-exercise, and during oxygen supplementation, composite score was lower at 14,000 ft than at 10,000 ft. This indicates that 14,000 ft is above the threshold at which decrements in cognitive performance become significant. The improvements in performance on tests taken post-exercise and during oxygen supplementation have implications that directly influence pilots. For those pilots of larger aircraft, where it is feasible to get up and move around, it may be beneficial to do so. Even for those confined to a small cockpit, it may be beneficial for them to engage in some activity that would increase their heart rate and cardiac output prior to mentally challenging portions of the flight. Results of this study indicate that all pilots flying above 10,000 ft could potentially benefit from the use of supplemental oxygen during flight.

Another important aspect of flight is the ability to accurately assess one's own abilities in the absence of external feedback to this effect. Notably, subjects were not

able to accurately predict their performance on the task used in this study. If the same holds true in a flight situation, this could become significant. Although the post-test predictions were more accurate (especially with the composite score feedback), in a flying situation the key is not how accurately a pilot rates his/her performance after landing, but rather what is going on before that. The more accurate post-test estimations while on oxygen at 14,000 ft also point towards the benefits of oxygen supplementation on self-awareness and performance.

The preliminary data found in this study point to several other areas for further research. First, the power calculation for 10 subjects and an assumed effect size of 0.2 (small), yields a power of 0.10. Due to the small effect size, inherent in cognitive assessment, this study could benefit from three to four times the number of subjects to increase the power and the strength of the conclusions.

Second, to further explain the performance difference between 10,000 ft and 14,000 ft, it would be beneficial to have subject perform a ground level run following the protocol used for the altitude exposures. By examining the scores at ground level compared with those at altitude, it would be possible to see whether performance is for some reason increased at 10,000 ft (as was the case under resting conditions) and how the scores at 14,000 ft under all conditions compare to those at ground level.

To evaluate the original hypothesis of decreased performance with lowered SaO_2 levels due to exercise, it would be necessary to test subjects while they were performing the exercise as opposed to during the recovery period. It would also be interesting to investigate the minimum amount of exercise necessary to produce the improvements in performance found here, for applications to pilots.

Finally, to more accurately investigate the difference between estimation and performance and implications for pilots, a similar study could be conducted using a flight simulator rather than the task used here. Besides the added component of specificity, the feedback received from the flight panel (such as altitude, course heading etc.) would be more realistic regarding what the pilot had to base his/her post-performance questionnaires on. This would improve the validity of the post-performance estimation and how it compares to actual performance.

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APPENDIX A

COLORADO STATE UNIVERSITY
INFORMED CONSENT TO PARTICIPATE IN A RESEARCH PROJECT

TITLE OF PROJECT: Perceived and Actual Cognitive Changes at Mild Levels of Hypoxia

NAME OF PRINCIPAL INVESTIGATOR: Alan Tucker, Ph.D.

NAME OF CO-INVESTIGATOR: Laura Terry

CONTACT NAME AND PHONE NUMBER FOR QUESTIONS/PROBLEMS: Laura Terry, (970)223-3141

SPONSOR OF PROJECT: Department of Physiology

PURPOSE OF THE RESEARCH:

The purpose of this research project is to study the effects of mild hypoxia (low oxygen levels) on perceived and actual changes in performance of simple mental and physical tasks and problem solving. Results may be useful to pilots of civilian and military aircraft who may operate in unpressurized aircraft below 14,000 ft, personnel who work in mines or astronomical observatories at high altitudes, and mountain climbers who are active at such altitudes.

PROCEDURES/METHODS TO BE USED:

During this research project, you will be asked for a total time commitment of seven hours on two separate days (three hours per day plus one training session). You may not test on consecutive days but you will be asked to complete all testing in less than 10 days. All testing will be conducted during the same half of the day, either morning or afternoon. We will schedule all sessions around your schedule.

The first day will begin with a practice session to allow you to become proficient at the cognitive test you will be asked to perform in the following sessions. The test is a synthetic work task known as SynWin, which is a computer based set of tasks involving memory, arithmetic processing, and visual and auditory monitoring. You will become familiar with the four sub-tasks of the SynWin during the practice session.

During the testing sessions on the first and second days you will be exposed to a simulated altitude of either 10,000 ft or 14,000 ft alternately. During the two test sessions, you will be tested under four (4) different test conditions where you must perform the SynWin. You will be exposed and tested under the following conditions:

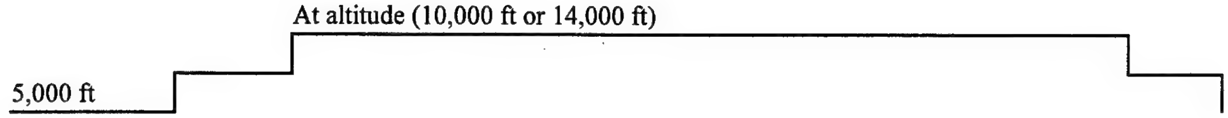
1. At ground level (5,000 ft) under resting conditions.
2. At altitude under resting conditions.
3. At altitude after 15 minutes of moderate exercise.
4. At altitude on 100% supplemental oxygen under resting conditions.

During the exposures, your blood oxygen levels and heart rate will be measured using a sensor that clips to your finger, while you are performing the SynWin test. The same measurements will be taken during the exercise portion of the exposure.

You will also fill out a short questionnaire before and after performing the SynWin at each condition, predicting your performance on that test session. You can stop the testing procedures at any time during the course of the research.

Inside the chamber, you will be asked to sit quietly for the first two test conditions. For the third condition, you will be asked to perform a step test at a predetermined pace for 10 minutes. The third test session will be conducted following this exercise. For the final condition, you will first be asked to breathe 100%

oxygen for 10 minutes which will be delivered via an oxygen mask. You will continue to breathe oxygen while performing the final test session. All oxygen equipment will be sterilized before your exposure. There will be a researcher inside the chamber with you at all times. A sample profile of an exposure is shown below:



Minute	-15 0	10	25	30	45	50	60	65	80	85	95	100	115	120	130
Condition	Resting	Ascent			Resting		Exercise		Post-Ex.		O2 Supp.		O2 Supp.		Descent
Activity	SynWin			Q1	SynWin	Q2		Q1	SynWin	Q2		Q1	SynWin	Q2	
Measurements	O2/HR				O2/HR		O2/HR		O2/HR		O2/HR		O2/HR		

SynWin: Test administered
Q1: Pre-test perception questionnaire
Q2: Post-test perception questionnaire
O2: O2 saturation measurement
HR: Heart rate measurement

RISKS INHERENT IN THE PROCEDURES:

Because this is a research project, there are some minimal risks associated with your participation. You will be exposed to a hypobaric (decreased atmospheric pressure due to increased altitude) environment of 14,000 ft for up to three hours. Potential risks include acute mountain sickness with symptoms such as nausea, vomiting, headache, and gastrointestinal disturbances. There is considerable individual variation in regards to the possibility of suffering from mountain sickness. Although an elevation of 10,000 ft may produce symptoms in some people, others may not show any signs up to 19,000 ft. About 19,000 ft such symptoms become relatively more common. You will be asked to fill out a short medical history questionnaire when you first volunteer to screen you for possible risks. Prior to all exposures you will again be questioned to ensure safety during the exposure. In case you experience such symptoms, supplemental oxygen will be available at all times which should alleviate any problems. If problems persist, you will be let out of the main altitude chamber and returned to ground level within 10 minutes.

Hartshorn Health Service medical personnel have been advised concerning the protocol of this study. Physicians will be advised at the start of all exposures and will be available should the need arise.

You may feel claustrophobic during the research due to the confined space of the altitude chamber.

Other possible risks include cerebral edema (fluid in the brain), pulmonary edema (fluid in the lungs), light-headedness, dizziness, headache, and nausea. These may be MINIMIZED OR ELIMINATED by breathing 100% oxygen if needed.

There are no known risks of psychological trauma or stress. There are no known legal risks involved with your participation.

Page 2 of 4 Subject initials _______ Date _______

APPENDIX A

It is not possible to identify all potential risks in research procedures, but the researcher(s) have taken reasonable safeguards to minimize any known and potential, but unknown, risks. The risks are summarized below:

Possible Risks Associated with Altitude Exposure:	Likelihood of Occurrence:	Steps Taken To Avoid/Minimize Risk:
Cerebral edema (Fluid in the brain)	Minimized/eliminated	14,000 ft maximum altitude
Pulmonary edema (Fluid in the lungs)	Minimized/eliminated	14,000 ft maximum altitude
Light-headedness, dizziness, headache, nausea	Minimized/eliminated	14,000 ft maximum altitude
Hypoxia (Decreased oxygen to the brain)	Minimized/eliminated	14,000 ft maximum altitude
Acute Mountain Sickness	Minimal	14,000 ft maximum altitude
Claustrophobia	Minimal	Participants screened prior to start
Loss of confidentiality	Minimal	Use a subject number instead of name
Social/economic harm	Minimal	N/A
Legal risk	No Known Risks	N/A
Psychological trauma or stress	No Known Risks	N/A

BENEFITS:

The results of this study may be beneficial in improving flight safety in unpressurized aircraft and helicopters, improve safety for high altitude workers in mines and astronomical observatories as well as for mountain climbers. There are no direct benefits to you.

CONFIDENTIALITY:

All data collected will be used for the sole purpose of this research project. No personal information, other than the raw data collected during the research, will be released to any agency or person. Data collection will be done by assigning each volunteer a subject number and no reference will be made as to your identity.

LIABILITY:

Because Colorado State University is a publicly funded state institution, it may have only limited legal responsibility for injuries incurred as a result of participation in this study under a Colorado law known as the Colorado Governmental Immunity Act (Colorado Revised Statutes, Section 24-10-101, et seq.). In addition, under Colorado law, you must file any claims against the University within 180 days after the date of the injury.

In light of these laws, you are encouraged to evaluate your own health and disability insurance to determine whether you are covered for any physical injuries or emotional distresses you might sustain by participating in this research, since it may be necessary for you to rely on your individual coverage for any such injuries. Some health care coverages will not cover research-related expenses. If you sustain injuries which you believe were caused by Colorado State University or its employees, we advise you to consult an attorney.

Questions concerning treatment of subjects' rights may be directed to Celia S. Walker at (970) 491-1563.

Page 3 of 4 Subject initials _______ Date _______

PARTICIPATION:

Your participation in this research is voluntary. If you decide to participate in the study, you may withdraw your consent and stop participating at any time without penalty or loss of benefits to which you are otherwise entitled.

Your signature acknowledges that you have read the information stated and willingly sign this consent form. Your signature also acknowledges that you have received, on the date signed, a copy of this document containing 4 pages.

____
Participant name (printed)

______________________________ ________________
Participant signature Date

______________________________ ________________
Witness to signature (project staff) Date

Page 4 of 4 Subject initials _______ Date _______

APPENDIX B

Initial Screening for Participation

Subject Number: ____________________

Date: ____________________

Age: ________

Weight: ________

Sex: M F

Please circle YES or NO for the following questions.

To the best of your knowledge:

1. Are you medically prevented from flying? YES NO
   If yes, for what:

2. Are you claustrophobic? YES NO

3. Are you currently under the care of a physician? YES NO
   If yes, for what:

4. Are you currently taking any medications? YES NO
   If yes, what:

5. Have you had any recent dental work? YES NO
   If yes, what:

6. Have you ever had a collapsed lung? YES NO

7. Have you had prior problems in the altitude chamber or aircraft with decompression sickness, ears, sinuses, or claustrophobia? YES NO
   If yes, what:

8. Are you pregnant? **FEMALE ONLY!!** YES NO

7. Have you ever been diagnosed with any type of lung or heart condition? YES NO
   If yes, what:

8. Have you ever had any type of eye surgery (PRK, LASIK etc)? YES NO
   If yes, please explain:

9. Is there anything the researchers should be aware of in regards to your health? YES NO
   If yes, what:

Researcher's Signature: ____________________

APPENDIX C

"HOW ARE YOU"		
SUBJECT #:	EXPOSURE PROFILE #:	DATE:

PLEASE EXPLAIN ANY MEDICAL PROBLEMS (with history) AT BOTTOM OF PAGE!

	YES	NO
1. Are you having difficulties in performing the valsalva maneuver (clearing your ears)?	☐	☐
2. Have you taken medication or received immunizations in the past 24 hours? *If YES, specify type and reason:*	☐	☐
3. Have you had recent dental work (within the last 72 hours)?	☐	☐
4. Have you donated blood within the last 72 hours?	☐	☐
5. Have you been SCUBA or surface supplied diving, or had a hyperbaric (dive) chamber exposure within the last 24 hours?	☐	☐

6. Do you presently have (or recently had) any of the following?

- ☐ Abdominal Pain/Nausea
- ☐ Aching Muscles/Joints
- ☐ Diarrhea/Constipation
- ☐ Ear Problems
- ☐ Muscular/Skeletal Injuries
- ☐ TB
- ☐ Dehydration
- ☐ Coughing
- ☐ Tooth pain
- ☐ Hangover
- ☐ Hay fever/Allergy Problems
- ☐ Headaches/Nausea/Vomiting
- ☐ Sinusitis/Cold

	YES	NO
13. Are there any other conditions you feel we should be aware of?	☐	☐
14. Have you been to less than 5,000 ft in the last two weeks?	☐	☐

COMMENTS:

RESEARCHER REVIEW:

APPENDIX D

Pre-task Performance Estimate Questionnaire
SynWin Testing Session

Subject #: ______ Exposure #: _____ Trial #: ____ Date/Time: ____

Section scores will be composed of points awarded for correct answers minus those subtracted for incorrect answers.

Dwell time is the approximate amount of time the mouse pointer is in the task window for the task.

Percent correct is the number answered correctly over the total number answered.

Lapses are the number of times a stimulus will be missed.

Scale:

Decreased Performance		No Change	Increased Performance	
1	2	3	4	5

Memory Task

	Lower Score			Higher Score	
Compared to my last trial, my section score **will be:**	1	2	3	4	5
	Longer			Shorter	
Compared to my last trial, dwell time **will be:**	1	2	3	4	5
	Less			More	
Compared to my last trial, my percent correct **will be:**	1	2	3	4	5

Math Task

	Lower Score			Higher Score	
Compared to my last trial, my section score **will be:**	1	2	3	4	5
	Longer			Shorter	
Compared to my last trial, dwell time **will be:**	1	2	3	4	5
	Less			More	
Compared to my last trial, my percent correct **will be:**	1	2	3	4	5

APPENDIX D

Visual Monitoring

	Lower Score			Higher Score	
Compared to my last trial, my section score **will be**:	1	2	3	4	5
	Longer			Shorter	
Compared to my last trial, dwell time **will be**:	1	2	3	4	5
	More			Less	
Compared to my last trial, my lapses **will be:**	1	2	3	4	5

Auditory Monitoring

	Lower Score			Higher Score	
Compared to my last trial, my section score **will be**:	1	2	3	4	5
	Longer			Shorter	
Compared to my last trial, dwell time **will be**:	1	2	3	4	5
	More			Less	
Compared to my last trial, my lapses **will be:**	1	2	3	4	5

Overall Performance

	Lower Score			Higher Score	
Compared to my last trial, my total score **will be**:	1	2	3	4	5
	More Difficult			Easier	
Compared to my last trial, the test difficulty **will be**:	1	2	3	4	5
	Less			Greater	
Compared to my last trial, my effort **will be:**	1	2	3	4	5

APPENDIX E

Post-task Performance Estimate Questionnaire
SynWin Testing Session

Subject #: ______ Exposure #: ______ Trial #: ______ Date/Time: ____

***Note: Estimate does NOT have to agree with Pre-Task estimation.**

Section Scores will be composed of points awarded for correct answers minus those subtracted for incorrect answers.

Dwell time is the approximate amount of time the mouse pointer is in the task window for the task.

Percent correct is the number answered correctly over the total number answered.

Lapses are the number of times a stimulus was missed.

Scale:

Decreased Performance		No Change	Increased Performance	
1	2	3	4	5

Memory Task

	Lower Score			Higher Score	
Compared to my last trial, my section score **was:**	1	2	3	4	5
	Longer			Shorter	
Compared to my last trial, dwell time **was:**	1	2	3	4	5
	Less			More	
Compared to my last trial, my percent correct **was:**	1	2	3	4	5

Math Task

	Lower Score			Higher Score	
Compared to my last trial, my section score **was:**	1	2	3	4	5
	Longer			Shorter	
Compared to my last trial, dwell time **was:**	1	2	3	4	5
	Less			More	
Compared to my last trial, my percent correct **was:**	1	2	3	4	5

APPENDIX E

Visual Monitoring

	Lower Score				Higher Score
Compared to my last trial, my section score **was**:	1	2	3	4	5
	Longer				Shorter
Compared to my last trial, dwell time **was**:	1	2	3	4	5
	More				Less
Compared to my last trial, my lapses **were:**	1	2	3	4	5

Auditory Monitoring

	Lower Score				Higher Score
Compared to my last trial, my section score **was**:	1	2	3	4	5
	Longer				Shorter
Compared to my last trial, dwell time **was**:	1	2	3	4	5
	More				Less
Compared to my last trial, my lapses **were:**	1	2	3	4	5

Overall Performance

	Lower Score				Higher Score
Compared to my last trial, my total score **was**:	1	2	3	4	5
	More Difficult				Easier
Compared to my last trial, the test difficulty **was**:	1	2	3	4	5
	Less				Greater
Compared to my last trial, my effort **was:**	1	2	3	4	5

Test Variance

Did your performance significantly differ between the three test sessions?	Yes		No
	Worst		Best
If yes, rate your performance on the three tests from best to worse:	_____	_____	_____

APPENDIX F
SYNWIN DATA SUMMARY

Exposure **10,000 ft**

Trial		0	1	2	3
Composite	1	949	1243	1180	1185
	2	**1052**	**1045**	**1057**	**1224**
	3	647	713	710	675
	4	**1303**	**1337**	**1315**	**1356**
	5	912	978	1071	1047
	6	**855**	**934**	**1073**	**1152**
	7	1258	1289	1292	1337
	8	**981**	**1072**	**935**	**1048**
	9	598	776	765	674
	10	**599**	**584**	**672**	**618**
Memory	1	63	257	230	170
	2	**257**	**253**	**270**	**290**
	3	263	257	193	240
	4	**270**	**270**	**270**	**277**
	5	213	203	147	190
	6	**223**	**250**	**257**	**260**
	7	270	290	277	283
	8	**237**	**263**	**190**	**237**
	9	187	257	223	217
	10	**233**	**257**	**267**	**233**
Math	1	633	753	667	827
	2	**600**	**567**	**567**	**680**
	3	140	233	247	200
	4	**807**	**847**	**780**	**833**
	5	487	553	640	640
	6	**433**	**467**	**573**	**630**
	7	740	787	733	800
	8	**533**	**593**	**480**	**587**
	9	200	293	287	247
	10	**160**	**107**	**173**	**120**

Exposure **14,000 ft**

Trial		0	1	2	3
Composite	1	831	973	1017	1114
	2	**1055**	**944**	**1118**	**1166**
	3	601	587	709	487
	4	**1054**	**1090**	**1238**	**1111**
	5	886	820	830	1024
	6	**1083**	**1136**	**1206**	**1340**
	7	908	1085	1215	1194
	8	**730**	**813**	**931**	**774**
	9	485	521	505	637
	10	**618**	**644**	**748**	**710**
Memory	1	110	163	123	210
	2	**277**	**250**	**270**	**277**
	3	160	210	203	180
	4	**243**	**253**	**263**	**250**
	5	200	120	157	217
	6	**230**	**230**	**237**	**270**
	7	263	250	267	270
	8	**210**	**197**	**210**	**170**
	9	190	203	140	167
	10	**253**	**283**	**277**	**277**
Math	1	513	580	647	627
	2	**580**	**480**	**613**	**640**
	3	247	207	287	140
	4	**600**	**600**	**753**	**613**
	5	487	480	427	573
	6	**620**	**687**	**713**	**827**
	7	453	600	707	653
	8	**333**	**387**	**493**	**367**
	9	113	113	147	213
	10	**120**	**133**	**187**	**187**

APPENDIX F
SYNWIN DATA SUMMARY

Exposure **10,000 ft**

	Trial	0	1	2	3
Visual	1	132	133	126	68
	2	**112**	**115**	**117**	**114**
	3	130	130	130	128
	4	**120**	**134**	**135**	**132**
	5	122	122	124	117
	6	**122**	**128**	**130**	**127**
	7	132	113	128	134
	8	**117**	**115**	**122**	**118**
	9	114	126	95	118
	10	**123**	**111**	**129**	**124**
Auditory	1	120	100	157	120
	2	**83**	**110**	**103**	**140**
	3	113	93	140	107
	4	**107**	**87**	**130**	**113**
	5	90	100	160	100
	6	**77**	**90**	**113**	**135**
	7	117	100	153	120
	8	**93**	**100**	**143**	**107**
	9	97	100	160	93
	10	**83**	**110**	**103**	**140**

Exposure **14,000 ft**

	Trial	0	1	2	3
Visual	1	128	123	134	130
	2	**118**	**124**	**121**	**120**
	3	128	124	129	127
	4	**131**	**123**	**132**	**127**
	5	129	113	120	121
	6	**120**	**126**	**113**	**126**
	7	118	119	128	124
	8	**117**	**116**	**114**	**111**
	9	105	115	118	124
	10	**128**	**131**	**132**	**127**
Auditory	1	80	107	113	147
	2	**80**	**90**	**113**	**130**
	3	67	47	90	40
	4	**80**	**113**	**90**	**120**
	5	70	107	127	113
	6	**113**	**93**	**143**	**117**
	7	73	117	113	147
	8	**70**	**113**	**113**	**127**
	9	77	90	100	133
	10	**117**	**97**	**153**	**120**

APPENDIX G
TRIAL DIFFERENCES AND ESTIMATION RATINGS

10,000 ft

Trial 1		**Subject** 1	**2**	3	**4**	5	**6**	7	**8**	9	**10**
Composite	Diff	142	**-111**	66	**34**	67	**79**	177	**91**	178	**-15**
Composite	Pre	1	**0**	-1	**0**	0	**0**	-1	**0**	-1	**-1**
Composite	Post	1	**-1**	0	**0**	-1	**1**	1	**1**	1	**0**
Memory	Diff	53	**-27**	-7	**0**	-10	**27**	-13	**27**	70	**23**
Memory	Pre	1	**0**	-1	**-1**	0	**1**	-1	**0**	-1	**-1**
Memory	Post	1	**-1**	0	**0**	-1	**1**	0	**1**	1	**0**
Math	Diff	67	**-100**	93	**40**	67	**33**	147	**60**	93	**-53**
Math	Pre	1	**0**	-1	**0**	0	**1**	-1	**0**	-1	**-1**
Math	Post	1	**-1**	0	**-1**	-1	**1**	1	**1**	1	**-1**
Visual	Diff	-5	**5**	0	**14**	0	**6**	1	**-2**	11	**-12**
Visual	Pre	0	**0**	-1	**0**	0	**1**	0	**0**	0	**0**
Visual	Post	0	**0**	0	**0**	0	**1**	1	**1**	1	**0**
Auditory	Diff	27	**10**	-20	**-20**	10	**13**	43	**7**	3	**27**
Auditory	Pre	0	**0**	-1	**0**	0	**0**	0	**0**	-1	**0**
Auditory	Post	0	**-1**	0	**0**	0	**1**	1	**1**	0	**0**

Trial 2		**Subject** 1	**2**	3	**4**	5	**6**	7	**8**	9	**10**
Composite	Diff	44	**174**	-3	**-23**	93	**139**	129	**-137**	-10	**88**
Composite	Pre	0	**0**	-1	**0**	1	**0**	0	**0**	0	**-1**
Composite	Post	0	**1**	-1	**0**	1	**1**	1	**0**	0	**0**
Memory	Diff	-40	**20**	-63	**0**	-57	**7**	17	**-73**	-33	**10**
Memory	Pre	0	**0**	-1	**-1**	1	**1**	0	**0**	0	**-1**
Memory	Post	0	**1**	-1	**0**	1	**1**	0	**0**	0	**0**
Math	Diff	67	**133**	12	**-67**	87	**107**	107	**-113**	-7	**67**
Math	Pre	0	**0**	-1	**0**	1	**0**	0	**0**	0	**-1**
Math	Post	-1	**1**	0	**0**	0	**1**	1	**0**	1	**0**
Visual	Diff	11	**-2**	0	**1**	3	**2**	9	**6**	-30	**18**
Visual	Pre	0	**0**	0	**0**	1	**0**	0	**0**	0	**0**
Visual	Post	0	**0**	0	**0**	0	**1**	0	**0**	-1	**1**
Auditory	Diff	7	**23**	47	**43**	60	**23**	-3	**43**	60	**-7**
Auditory	Pre	0	**0**	-1	**0**	1	**0**	0	**0**	0	**-1**
Auditory	Post	1	**1**	0	**0**	0	**0**	1	**0**	0	**-1**

APPENDIX G
TRIAL DIFFERENCES AND ESTIMATION RATINGS

10,000 ft

Trial 3		Subject									
		1	2	3	4	5	6	7	8	9	10
Composite	Diff	96	48	-35	41	-24	79	-20	113	-91	-55
Composite	Pre	1	1	1	0	1	0	1	0	1	1
Composite	Post	1	1	0	1	1	1	-1	0	0	-1
Memory	Diff	87	7	47	7	43	3	3	47	-7	-33
Memory	Pre	1	1	1	0	0	1	0	0	0	1
Memory	Post	1	1	0	1	0	1	-1	0	0	-1
Math	Diff	-20	27	-47	53	0	57	-53	107	-40	-53
Math	Pre	1	1	1	0	1	1	1	0	0	0
Math	Post	1	1	0	0	0	0	-1	0	-1	-2
Visual	Diff	-4	-2	-2	-2	-8	-3	-4	-4	22	-5
Visual	Pre	0	1	0	0	1	0	0	0	1	1
Visual	Post	0	1	0	0	0	1	0	0	0	0
Auditory	Diff	33	17	-33	-17	-60	22	33	-37	-67	37
Auditory	Pre	0	1	0	0	1	1	0	0	1	0
Auditory	Post	-1	1	0	0	1	1	0	0	0	0

APPENDIX G
TRIAL DIFFERENCES AND ESTIMATION RATINGS

14,000 ft

Trial 1

		Subject 1	2	3	4	5	6	7	8	9	10
Composite	Diff	294	-7	-14	36	-66	53	31	83	36	26
Composite	Pre	1	-1	-1	-1	0	0	-1	-1	-1	-1
Composite	Post	2	-1	-1	0	0	1	-1	1	-1	-1
Memory	Diff	193	-3	50	10	-80	0	20	-13	13	30
Memory	Pre	1	-1	-1	-1	-1	1	-1	0	-1	-1
Memory	Post	2	-1	-1	0	0	1	0	1	-1	1
Math	Diff	120	-33	-40	0	-7	67	47	53	0	13
Math	Pre	0	-1	-1	-1	0	1	-1	0	0	-1
Math	Post	2	-1	-1	-1	0	1	-1	1	-1	0
Visual	Diff	0	3	-4	-8	-16	6	-19	0	9	2
Visual	Pre	0	-1	0	0	0	1	0	0	-1	0
Visual	Post	0	0	0	0	-1	0	-1	1	0	0
Auditory	Diff	-20	27	-20	33	37	-20	-17	43	13	-20
Auditory	Pre	0	-1	-1	0	1	0	0	-1	-1	-1
Auditory	Post	0	-1	-1	0	-1	0	0	1	-1	0

Trial 2

		Subject 1	2	3	4	5	6	7	8	9	10
Composite	Diff	-63	12	121	148	10	70	2	118	-16	104
Composite	Pre	0	0	0	-1	1	0	-1	0	0	0
Composite	Post	-1	0	1	0	-1	0	1	0	1	1
Memory	Diff	-27	17	-7	10	37	7	-13	13	-63	-7
Memory	Pre	-1	0	0	-1	1	0	-1	0	0	0
Memory	Post	-1	0	1	0	-1	1	1	0	1	1
Math	Diff	-87	0	80	153	-53	27	-53	107	33	53
Math	Pre	0	0	0	-1	1	0	-1	0	0	-1
Math	Post	0	-1	1	0	-1	1	1	0	0	1
Visual	Diff	-6	2	5	8	7	-13	16	-2	4	1
Visual	Pre	0	0	0	0	1	0	0	0	0	0
Visual	Post	0	0	0	0	-1	0	1	0	1	0
Auditory	Diff	57	-7	43	-23	20	50	53	0	10	57
Auditory	Pre	0	0	0	0	2	0	0	0	0	0
Auditory	Post	0	0	0	0	0	0	0	0	0	0

APPENDIX G
TRIAL DIFFERENCES AND ESTIMATION RATINGS

14,000 ft

Trial 3		Subject									
		1	**2**	3	**4**	5	**6**	7	**8**	9	**10**
Composite	Diff	5	**167**	-221	**-128**	194	**133**	45	**-157**	132	**-38**
Composite	Pre	1	**1**	0	**0**	1	**0**	1	**1**	0	**1**
Composite	Post	-1	**1**	-1	**-1**	1	**1**	0	**0**	1	**-1**
Memory	Diff	-60	**20**	-23	**-13**	60	**33**	7	**-40**	27	**0**
Memory	Pre	0	**1**	0	**0**	2	**0**	0	**1**	0	**1**
Memory	Post	0	**1**	-1	**0**	1	**1**	0	**0**	1	**0**
Math	Diff	160	**113**	-147	**-140**	147	**113**	67	**-127**	67	**0**
Math	Pre	1	**1**	0	**0**	1	**1**	1	**1**	1	**0**
Math	Post	-1	**1**	-1	**-1**	1	**1**	0	**0**	1	**0**
Visual	Diff	-58	**-3**	-1	**-4**	1	**13**	5	**-3**	5	**-5**
Visual	Pre	0	**1**	0	**0**	1	**0**	0	**0**	0	**1**
Visual	Post	0	**1**	0	**0**	1	**1**	0	**0**	1	**0**
Auditory	Diff	-37	**37**	-50	**30**	-13	**-27**	-33	**13**	33	**-33**
Auditory	Pre	0	**1**	0	**0**	2	**0**	0	**0**	1	**1**
Auditory	Post	-1	**1**	-1	**0**	0	**0**	0	**0**	1	**0**